AEC Category: HEALTH AND SAFETY

CEX-59.7B

CIVIL EFFECTS STUDY

EXPERIMENTAL RADIATION MEASUREMENTS IN CONVENTIONAL STRUCTURES

Part II

COMPARISON OF MEASUREMENTS IN ABOVE-GROUND AND BELOW-GROUND STRUCTURES FROM SIMULATED AND ACTUAL FALLOUT RADIATION

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COMPARISON OF MEASUREMENTS IN ABOVE-GROUND AND BELOW-GROUND STRUCTURES FROM SIMULATED AND ACTUAL FALLOUT RADIATION

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ABSTRACT

An experimental study designed to provide a basis for estimating protection against fallout radiation was made on two types of structures at the Nevada Test Site. ~~This study was sponsored by the Civil Effects Test Operations, Division of Biology and Medicine, U. S. Atomic Energy Commission.~~ The two buildings studied were a lightly constructed building with a basement, and an underground group shelter.

An idealized fallout radiation field was simulated by the use of the Mobile Radiological Measuring Unit (MRMU). The unit employed a sealed radioactive Co^{60} source that was pumped at a uniform speed through a long length of flexible tubing evenly distributed over the area of interest. Radiation levels at selected points inside the structures were measured with sensitive ionization-chamber detectors.

These measurements were compared with measurements taken under actual fallout conditions at an earlier time and were also compared with the theoretical calculations.

Protection factors from fallout data and MRMU data at the basement structure compared roughly within a factor of 2. This was good, considering the limitations of the two sets of data and other factors affecting the differences. Comparisons between protection factors from fallout data and MRMU data at the underground group shelter were excellent. MRMU data and theoretical calculations also compared satisfactorily.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

The Civil Effects Test Operations, Division of Biology and Medicine of the U. S. Atomic Energy Commission (AEC), has conducted a series of radiation measurements to evaluate the protection characteristics of conventional buildings, including underground structures and residential and office buildings.[1–6] A method of simulating an idealized fallout situation was developed for efficient field operations, and this method is fully described in Appendix A. The system was called the Mobile Radiological Measuring Unit (MRMU).

To give more reliability to these experimental measurements made with the MRMU, it was necessary to study structures in which radiation measurements had been made under actual fallout conditions. The comparison of the data provided information to correlate simulated and real fallout measurements.

During Operation Plumbbob a group from the New York Operations Office of the AEC conducted a series of measurements (Project 32.1) at a Butler building in Area 2 at the Nevada Test Site (NTS) under actual fallout conditions.[7] Measurements were taken with fallout deposited on the roof and on the ground outside the Butler building. The roof was then removed, and the measurements were repeated. The purpose was to measure the dose rate as contributed by fallout on the roof and as contributed by fallout on the ground outside the building.

Also during Operation Plumbbob, as part of Project 32.3, measurements were made inside an underground group shelter, having an earth-cover at least 3 ft thick, to determine the radiation level that resulted from fallout contamination on the ground outside the group shelter.[8]

The measurements presented in this report were made at these two structures at NTS by using the MRMU.

1.2 OBJECTIVES

The objectives of the experiment were

1. Evaluation of the fallout radiation protection provided by an underground group shelter and a Butler building with a basement when the MRMU was used as a method of simulation.
2. Comparison of data taken during actual fallout conditions at these structures to data taken with the MRMU.

1.3 DESCRIPTION OF THE STRUCTURES

The Butler building, with dimensions of 32 by 32 ft, was constructed of tin sheets on steel frames. The building contained a basement with a dirt floor. The ground-level floor consisted of a grid of 2 by 6's, with no floorboards. The steel framework was attached to a concrete foundation $1\frac{1}{2}$ ft thick. The top of the foundation was about 4 in. above ground level and 7.5 ft above basement-floor level. Figure 1.1 shows a general view of the building with tubing laced on the roof. Figures 1.2, 1.3, and 1.4 show the construction characteristics. The interior of the building is shown in Fig. 2.1.

The 100-man underground group shelter was constructed of a corrugated-steel arch set on a concrete slab, and the shelter proper was 3 ft or more below grade level. The shelter had been modified since Operation Plumbbob. A description of the original shelter can be found in Ref. 8. The shelter as it was for this program is shown in Figs. 1.5 and 1.6. Other views of the shelter are shown in Figs. 2.2 to 2.5.

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2. J. F. Batter, Jr., A. L. Kaplan, and E. T. Clarke, *An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building,* USAEC Report CEX-59.1, Technical Operations, Inc., May 1, 1959.
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5. Z. Burson and H. Borella, *Experimental Evaluation of the Radiation Protection Provided by an Earth-Covered Shelter,* USAEC Report CEX-60.6, Edgerton, Germeshausen & Grier, Inc., April 1961.
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7. A. J. Breslin, P. Loysen, and M. S. Weinstein, *Protection Against Fallout Radiation in a Simple Structure,* Project 32.1, Operation Plumbbob Report WT-1462, 1963.
8. W. E. Strope, *Evaluation of Countermeasure System Components and Operational Procedures,* USAEC Report WT-1464, Naval Radiological Defense Laboratory, Aug. 14, 1958.

Fig 1 1 — General view of Butler building

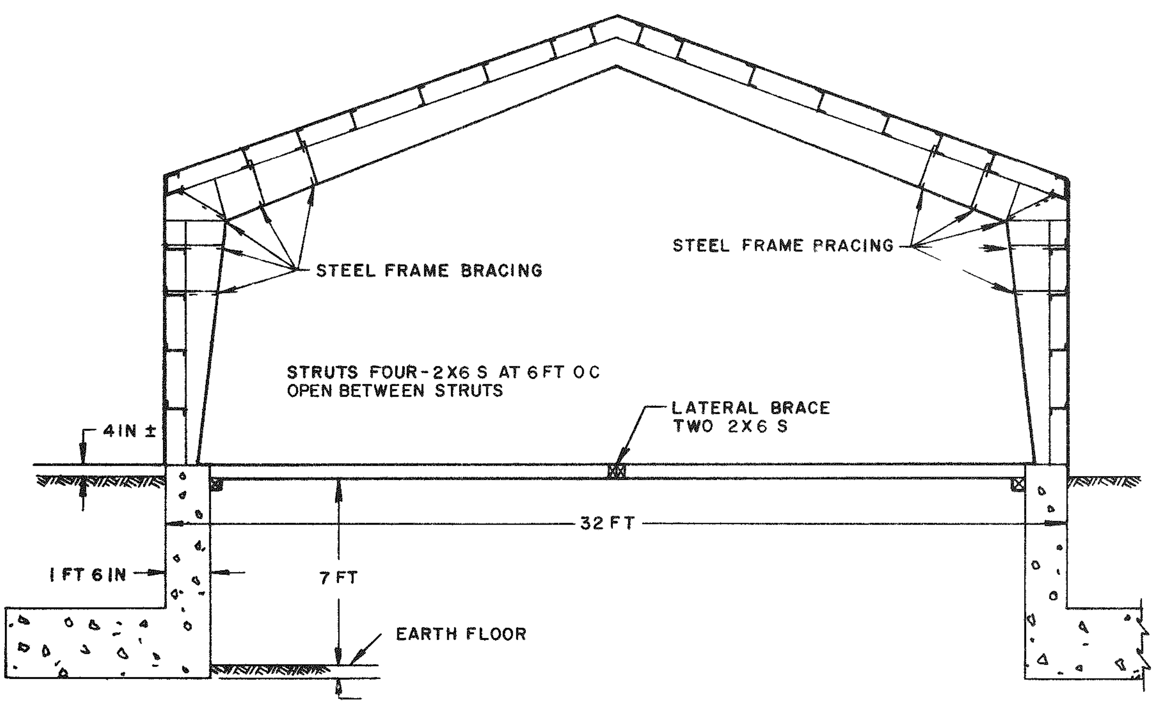
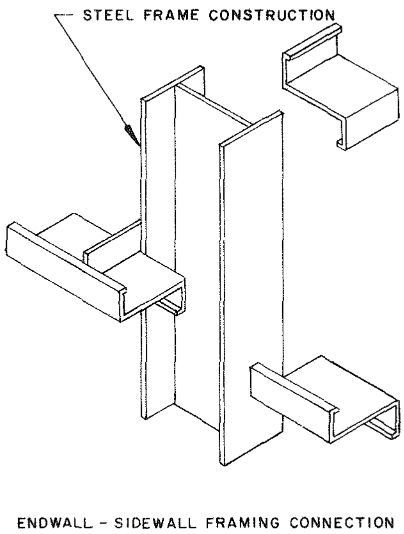


Fig 1.2 — Typical transverse section of Butler building



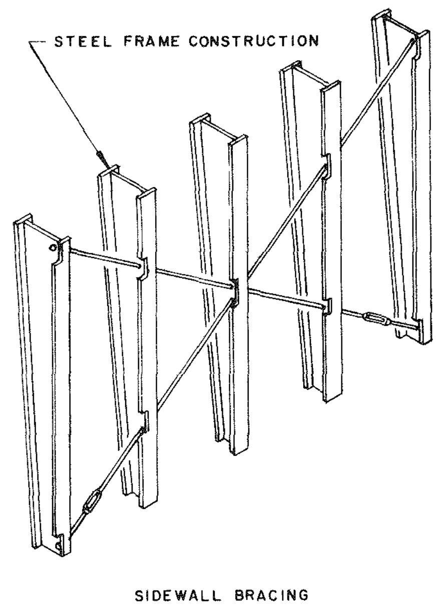


Fig. 1.3 — Typical framing construction of Butler building.

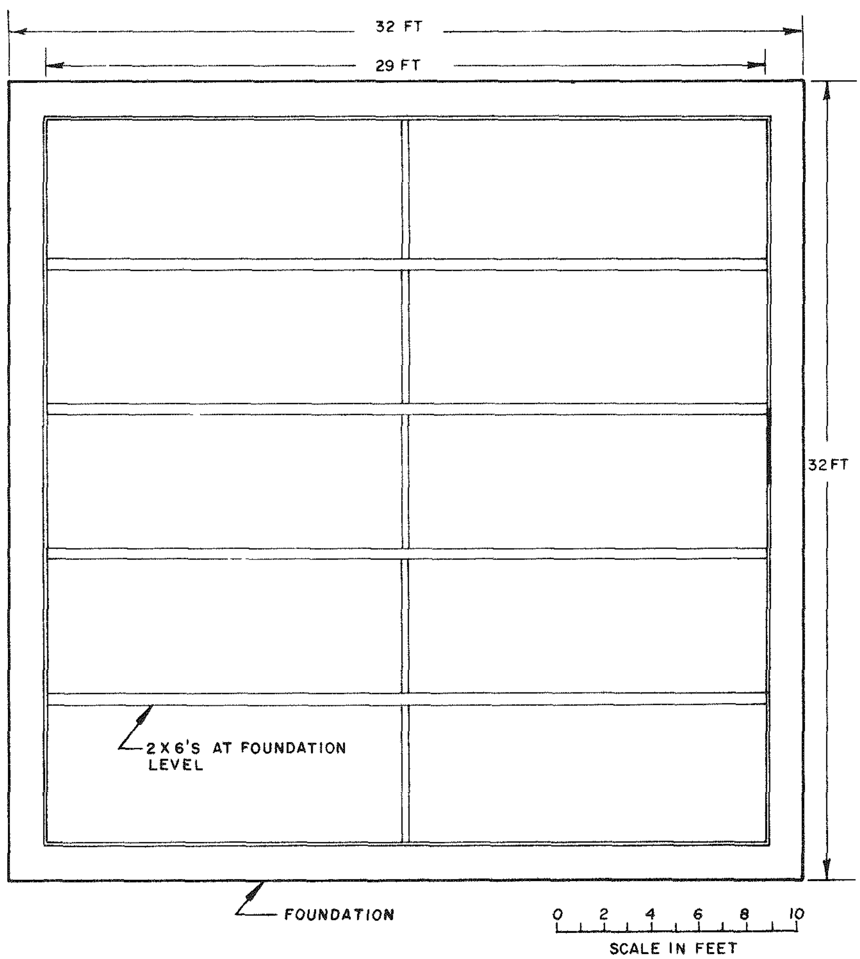


Fig. 1.4 — First-floor framework of Butler building.

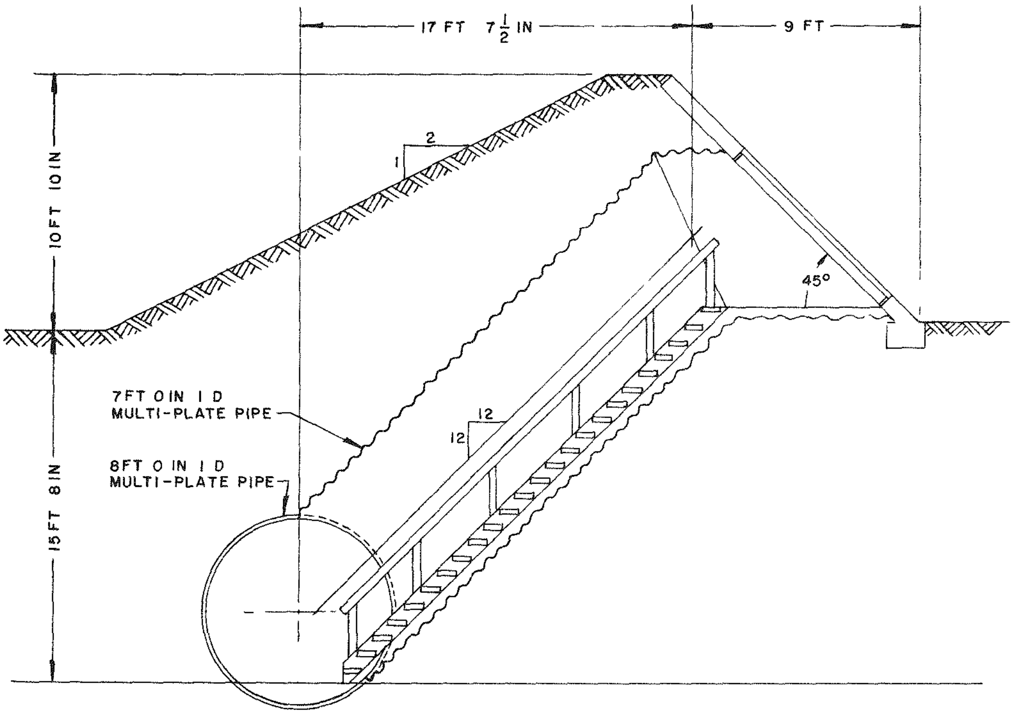


Fig. 1.5—Stairway to entrance of underground group shelter.

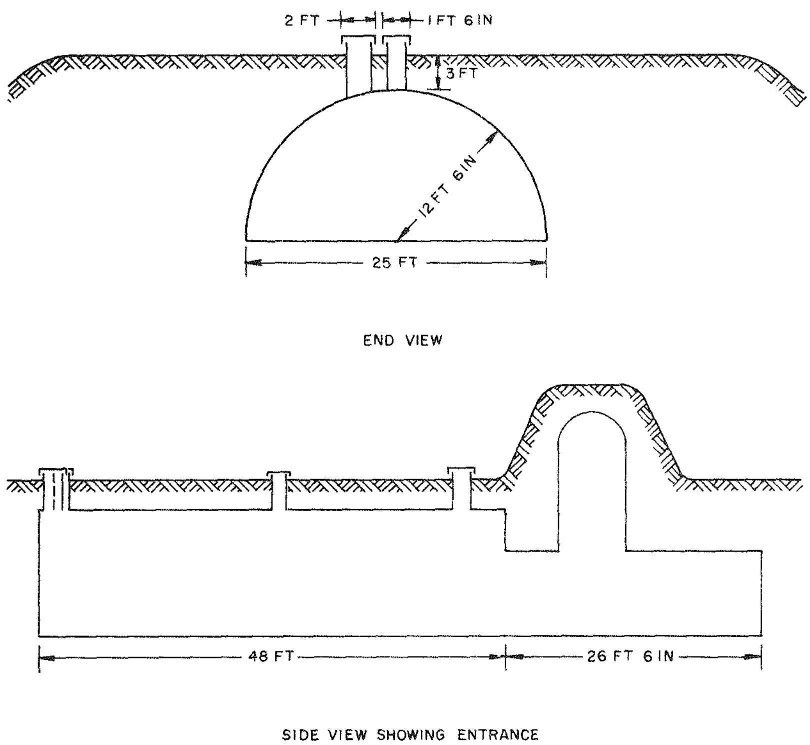


Fig. 1.6—Elevation views of underground group shelter.

Chapter 2

DESCRIPTION OF EXPERIMENTAL METHOD

2.1 GENERAL DESCRIPTION

Experimental data were taken at NTS to provide a basis for estimating the radiation protection provided by a Butler building with a basement and by an underground group shelter.

An idealized fallout radiation field was simulated by pumping a Co^{60} source through flexible plastic tubing that had been positioned over the desired area such that the amount of tubing per unit area was constant. The source traveled at a uniform speed as sensitive ionization-chamber detectors recorded the radiation dosage at selected locations within the structures. The MRMU, used to simulate the fallout radiation in this study, is described fully in Appendix A.

Radioactive Co^{60} sources used in this experiment included an 18.6-curie source, a 208-curie source, and a 259-curie source. Other sources were available but were not used during this project.

The 208-curie source was calibrated at NTS immediately prior to the experiment. The polyethylene tubing was placed over two 15-ft ladders. The source was pumped into position at a height of 12 ft and stopped while Victoreen condenser r-meters, previously cross-checked against chambers calibrated by the National Bureau of Standards, measured the dose rates at 10 and 15 ft from the source. At the time of calibration (May 3, 1960) the source was found to be 208 curies, assuming 14.53 r/hr/curie at 1 ft. Other sources were calibrated in the same manner.

2.2 EXPERIMENTAL TECHNIQUE

The experimental technique consisted in measuring the radiation dose at points within the building from a simulated contaminated area of known strength outside the building. Use of dose-integrating detectors within the building caused the total radiation dosage to appear to be arising from an area source. This technique had the advantage of averaging local features of the terrain and the building under test in much the same way as would be done in a true fallout field.

Before measurements were made, the polyethylene tubing was distributed according to a plan, a dummy source was pumped through the tubing to ensure that the tubing had not been damaged, and the dosimeters were charged and were placed at preselected locations. These detectors were placed in paper cups attached to strings hung either from the ceiling or from aluminum stands. When radiological-safety clearance was given, an exposure was made. At the conclusion of the exposure, the source was secured in its container, the dosimeters were read, and their readings were recorded.

The area surrounding the Butler building was not smoothed or otherwise disturbed. The experimental conditions were arranged as close to actual fallout conditions as was possible with the MRMU equipment.

To estimate the dose contribution from fallout on the roof of the Butler building, the tubing was spaced on the roof such that the tubing was 2 ft apart (Fig. 1.1). The 18.6-curie source was pumped through the tubing, and measurements were taken at several positions throughout the basement. Some of these positions are shown in Fig. 2.1 Five different measurements were made to aid in estimating the dose due to the ground contamination. A source geometry simulating a ring source rather than an area source was used. For the five ring-source measurements, the tubing was laid out in circles with radii of 25 5, 32.3, 42.5, 63 7, and 127 ft, the center of each circle coincided with the center of the building The 18.6-curie source was used for the 25.5-ft-radius measurement, the 208-curie source was used for the other four ring-source measurements.

The measurements of the underground group shelter were made with the tubing placed 4 ft apart over an area above and immediately surrounding the shelter (Figs. 2 2, 2 3, and 2.4) The 259-curie source was used for an exposure time of a little more than 2 hr, and the integrated dose was measured at several positions and heights inside the shelter (Fig. 2.5).

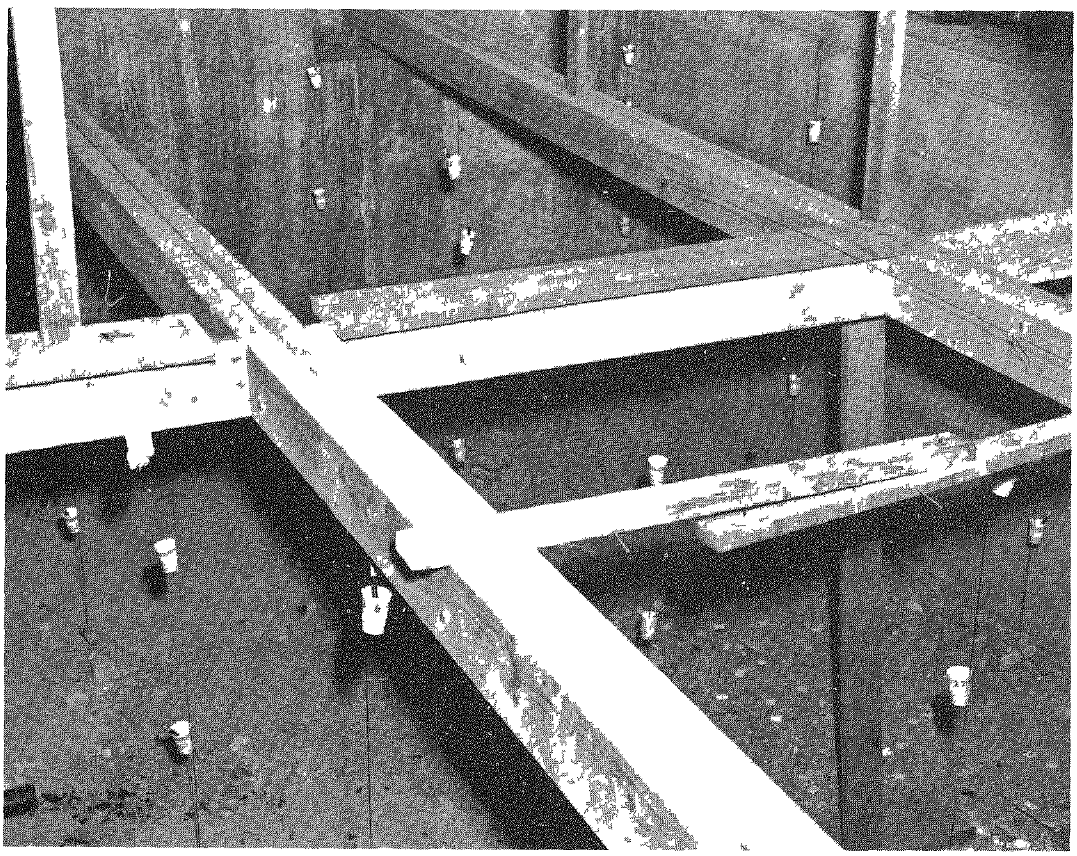


Fig 2 1—Dosimeter positions in basement of Butler building

Fig. 2.2 — Underground group shelter showing tubing layout over entrance.

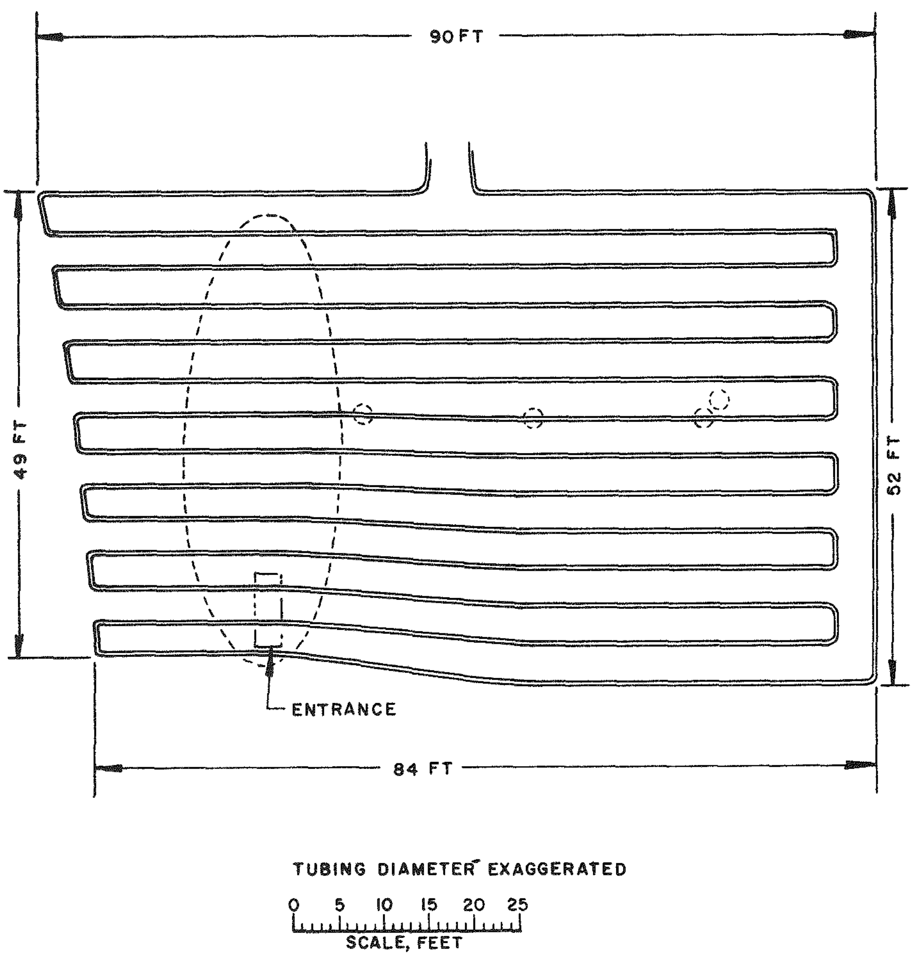


Fig. 2.3 — Tubing layout over underground shelter.

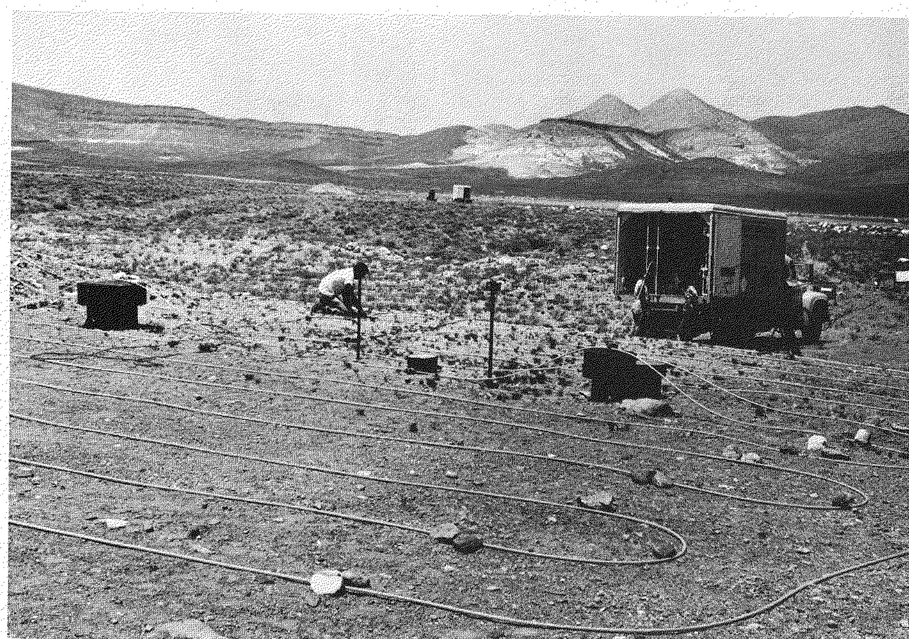


Fig. 2.4 — Tubing layout over top of underground shelter.

Fig. 2.5 — Dosimeters at various positions in underground shelter.

Chapter 3

PRESENTATION OF DATA

3.1 GENERAL

The data at each of the two structures are presented separately. Dosimeter locations in the structures are indicated by numbers on the floor plans, and the data at these positions are given in the tables. Data were taken at the 2-, 4-, and 6-ft levels at all positions in the Butler building and at the 3-ft level at all positions in the underground group shelter. Occasional readings were taken at other levels at a few of the positions. The readings at each point were corrected for background, temperature, pressure, and calibration and then normalized to milliroentgens per hour per millicurie per square foot or milliroentgens per hour per curie per foot, whichever was applicable. An indication is shown in the tables when the dosimeter readings were extremely low and therefore questionable. Table 3.1 includes some of the information pertinent to each exposure at each structure.

3.2 THE BUTLER BUILDING

A floor plan of the basement of the Butler building, together with dosimeter position numbers, is shown in Fig. 3.1. Two exposures were made with the tubing distributed on the roof. The normalized data were averaged, and these are presented in Table 3.2. Data normalized to milliroentgens per hour per curie per foot from ring sources of radii 25.5, 32.3, 42.5, 63.7, and 127 ft are shown in Tables 3.3 to 3.7. Data from the 127-ft radius were taken with the low-range ionization chambers (10 mr, full scale) and include only a few positions because of the limited number of chambers available. For information and comparative purposes, some of the data are presented in graphical form in Figs. 3.2 to 3.5.

3.3 THE UNDERGROUND GROUP SHELTER

An approximate floor plan of the underground group shelter, with dosimeter position numbers, is shown in Fig. 3.6. The data, as a function of position and height above the floor, were normalized to milliroentgens per hour per millicurie per square foot and are shown in Table 3.8.

TABLE 3.1 — EXPOSURE PARAMETERS

Type of run	Time of exposure, hr	Temp., °C	Pressure, mm Hg	Area, sq ft, or circumference, ft	Source strength, curies
			Butler Building		
Roof area	0.285	19	660	1088	18.6
	0.285	21	660	1088	18.6
25.5-ft radius	5.005	24	660	160	18.6
	0.515*				
32.3-ft radius	1.0844	13	653	203	208
	0.05944*				
42.5-ft radius	2.0167	10	653	267	208
	0.07306*				
63.7-ft radius	5.029	18	661	400	208
	0.1619*				
127-ft radius	0.9900	18	661	798	208
	0.5469	18	661	798	208
			Underground Group Shelter		
Ground area	2.0411	16	665	4500	279

* Aboveground measurement at position 38.

TABLE 3.2—DATA FOR ROOF OF BUTLER BUILDING

Position	Dose rate*					
	At 1 ft	At 2 ft	At 3 ft	At 4 ft	At 5 ft	At 6 ft
1	19	20	20	22	24	24
2		23		25		30
3		23		26		31
4		23		24		28
5		22		24		28
6	17	17	18	19	22	23
7		22		24		29
8	25	26	27	29	31	36
9		26		29		37
10		26		28		35
11	24	25	27	28	29	34
12		21		25		29
13		22		25		27
14		28		30		30
15		28		31		35
16		28		29		34
17		27		31		32
18		23		26		28
19		22				25
20		26				33
21		28				33
22		27				34
23		27				32
24		23				24
25		20				28
26	24	23	27	28	29	32
27		27				35
28		25				36
29	22	25	26	28	29	32
30		20				28
31	17	18	20	21	23	25
32		22				29
33		24				31
34		24				31
35		23				28
36	17	19	20	23	23	25
37	28	28	30	33	36	37
38†	46		58			

*Dose rate normalized to milliroentgens per hour per millicurie per square foot.

† Center of building, first floor, and heights above foundation.

TABLE 3.3—DATA FOR BUTLER BUILDING, USING 25.5-FT RADIUS

Position	Dose rate*					
	At 1 ft	At 2 ft	At 3 ft	At 4 ft	At 5 ft	At 6 ft
1	51	62	70	74	96	153
2		74		92		137
3		74		87		132
4		74		87		130
5		79		92		137
6	51	51	62	74	96	140
7		85		96		153
8	90	96	117	123	140	157
9		103		120		151
10		99		115		137
11	92	103	112	132	142	155
12		81		103		146
13		76		96		135
14		96		120		153
15		106		117		143
16		103		112		137
17		96		117		157
18		87		96		155
19		79		110		137
20		96		123		162
21		103		128		137
22		96		121		146
23		96		127		155
24		74		107		132
25		72		94		137
26	90	90	107	123	137	143
27		10		127		135
28		96		120		140
29	85	94	107	117	135	143
30		67		96		143
31	47	61	65	74	92	127
32		76		92		141
33		76		96		148
34		81		99		132
35		72		92		135
36	50	59	67	79	96	146
37	101	103	115	128	137	151
38†	790		2470		2560	2840‡

*Dose rate normalized to milliroentgens per hour per curie per foot.
†Center of building, first floor, and heights above foundation.
‡7 ft above foundation.

TABLE 3.4—DATA FOR BUTLER BUILDING, USING 32.3-FT RADIUS

Position	Dose rate*					
	At 1 ft	At 2 ft	At 3 ft	At 4 ft	At 5 ft	At 6 ft
1	37	44	47	54	68	93
2		57		68		104
3		55		66		97
4		55		58		89
5		56		66		94
6	38	42	46	50	64	89
7		56		68		103
8	66	70	77	92	103	115
9		74		89		112
10		71		85		102
11	58	70	80	87	102	112
12		56		68		100
13		56		68		101
14		72		92		117
15		78		92		113
16		78		85		106
17		69		89		116
18		55		70		106
19		56		71		102
20		68		90		124
21		78		94		110
22		71		90		113
23		70		92		116
24		55		74		98
25		49		65		101
26	63	62	78	89	101	112
27		79		93		103
28		70		90		109
29	58	68	76	87	100	105
30		49		68		102
31	34	44	46	54	63	84
32		54		68		102
33		56		70		106
34		56		70		101
35		54		68		97
36	35	44	47	56	69	94
37	70	78	86	93	103	115
38†	626		1860		1920	2050‡

*Dose rate normalized to milliroentgens per hour per curie per foot.
†Center of building, first floor, and heights above foundation.
‡7 ft above foundation.

TABLE 3.5—DATA FOR BUTLER BUILDING, USING 42.5-FT RADIUS

Position	Dose rate*					
	At 1 ft	At 2 ft	At 3 ft	At 4 ft	At 5 ft	At 6 ft
1	31	35	40	42	51	72
2		45		54		80
3		46		56		80
4		46		51		73
5		43		52		73
6	32	34	39	42	51	65
7		44		51		78
8	49	56	60	70	80	89
9		58		70		88
10		57		67		81
11	50	56	64	70	78	84
12		45		55		74
13		43		54		73
14		57		72		90
15		63		73		89
16		61		68		85
17		55		71		88
18		43		56		81
19		43		56		73
20		55		70		96
21		61		77		87
22		58		73		90
23		56		74		91
24		44		62		75
25		40		50		73
26	49	49	59	71	76	84
27		63		73		82
28		56		72		88
29	48	56	60	68	79	83
30		41		56		77
31	31	33	38	41	48	63
32		42		52		79
33		44		57		82
34		47		56		78
35		42		55		74
36	31	34	39	44	55	71
37	58	63	71	77	83	91
38†	442		1260		1370	1500‡

*Dose rate normalized to milliroentgens per hour per curie per foot.
†Center of building, first floor, and heights above foundation.
‡7 ft above foundation.

TABLE 3.6—DATA FOR BUTLER BUILDING, USING 63.7-FT RADIUS

Position	Dose rate* At 1 ft	At 2 ft	At 3 ft	At 4 ft	At 5 ft	At 6 ft
1	24	25	28	31	38	48
2		33		39		61
3		34		41		58
4		34		40		53
5		32		40		55
6	24	26	28	33	40	49
7		35		39		55
8	38	42	45	51	58	65
9		47		53		66
10		44		51		61
11	40	43	47	51	59	66
12		35		42		57
13		33		40		52
14		44		54		68
15		48		56		68
16		48		53		68
17		44		55		69
18		34		45		62
19		34		43		54
20		42		53		69
21		47		59		68
22		46		55		69
23		44		56		69
24		35		47		58
25		31		38		53
26	38	38	46	50	56	64
27		46		57		65
28		46		56		69
29	39	45	48	53	61	66
30		34		43		58
31	21	25	27	30	35	44
32		31		39		55
33		33		41		60
34		35		44		58
35		32		41		55
36	24	26	28	32	40	51
37	46	48	53	58	63	70
38†	428		932		1120	1130‡

*Dose rate normalized to milliroentgens per hour per curie per foot.
†Center of building, first floor, and heights above foundation.
‡7 ft above foundation.

TABLE 3.7 — DATA FOR BUTLER BUILDING, USING 127-FT RADIUS

Position	Dose rate*					
	At 1 ft	At 2 ft	At 3 ft	At 4 ft	At 5 ft	At 6 ft
1	16	17	18	21	24	32
2		21		26		37
3		23		28		37
7		21		26		38
8	24	26	28	33	40	45
9		28		35		48
13		22		28		36
14		28		36		48
15		31		39		48
37	28	32	35	39	44	50
38†	370		510		500	520‡

*Dose rate normalized to milliroentgens per hour per curie per foot.
†Center of building, first floor, and heights above foundation.
‡7 ft above foundation.

TABLE 3.8—DATA FOR UNDERGROUND SHELTER

Position	Dose rate* At 1 ft	At 3 ft	At 4 ft	At 5 ft	At 6 ft	At 7 ft	At 10 ft
1	0.010	0.0084					
2	0.046	0.064		0.10			
3							
4	0.020	0.018		0.016			
5	0.0073	0.0063					
6	0.0084	0.0073					
7	0.020	0.020		0.016			
8	0.087	0.074	0.072	0.060		0.059	
9	0.032	0.028		0.024			
10	0.012	0.0095					
11	0.0095	0.0073					
12	0.018	0.017		0.015			
13	0.028	0.028		0.025		0.028	
14	0.016	0.015		0.012			
15	0.0073	0.0063					
16	0.012	0.0063					
17	0.019	0.013		0.012			
18	0.049	0.048		0.041		0.038	
19	0.019	0.019		0.015			
20	0.0084	0.0073					
21	0.0073	0.0073					
22	0.022	0.018		0.018			
23			0.22		0.36		
24	0.018	0.017		0.015			
25	0.0084	0.0052					
26	0.0063	0.0042†					
27	0.012	0.012					
28	0.037	0.036		0.028			
29	0.012	0.012		0.0095			
30	0.0052	0.0052					
31	0.0042†	0.0032†					
32	0.0052	0.0042†		0.0042†			
33	0.0073	0.010		0.0052			
34	0.0084	0.0073		0.0042†			
35	0.0052	0.0042†					
36	0.0052	0.0052		0.0032†			
37	0.0063	0.018		0.0021†			
38	0.0073	0.0063		0.0032†			0.0021†
39	0.0063	0.0042†		0.0021†			
40	0.0052	0.0032†		0.0032†			
41	0.0063	0.0052		0.0010†			
42	0.0063	0.0032†		0.0021†			
43	0.026	0.021		0.0095			
44							
45							
46			0.90		1.1		
47			1.4		1.6		

*Dose rate normalized to milliroentgens per hour per millicurie per square foot.

† Low-range ionization chambers read 0.5 mr or less.

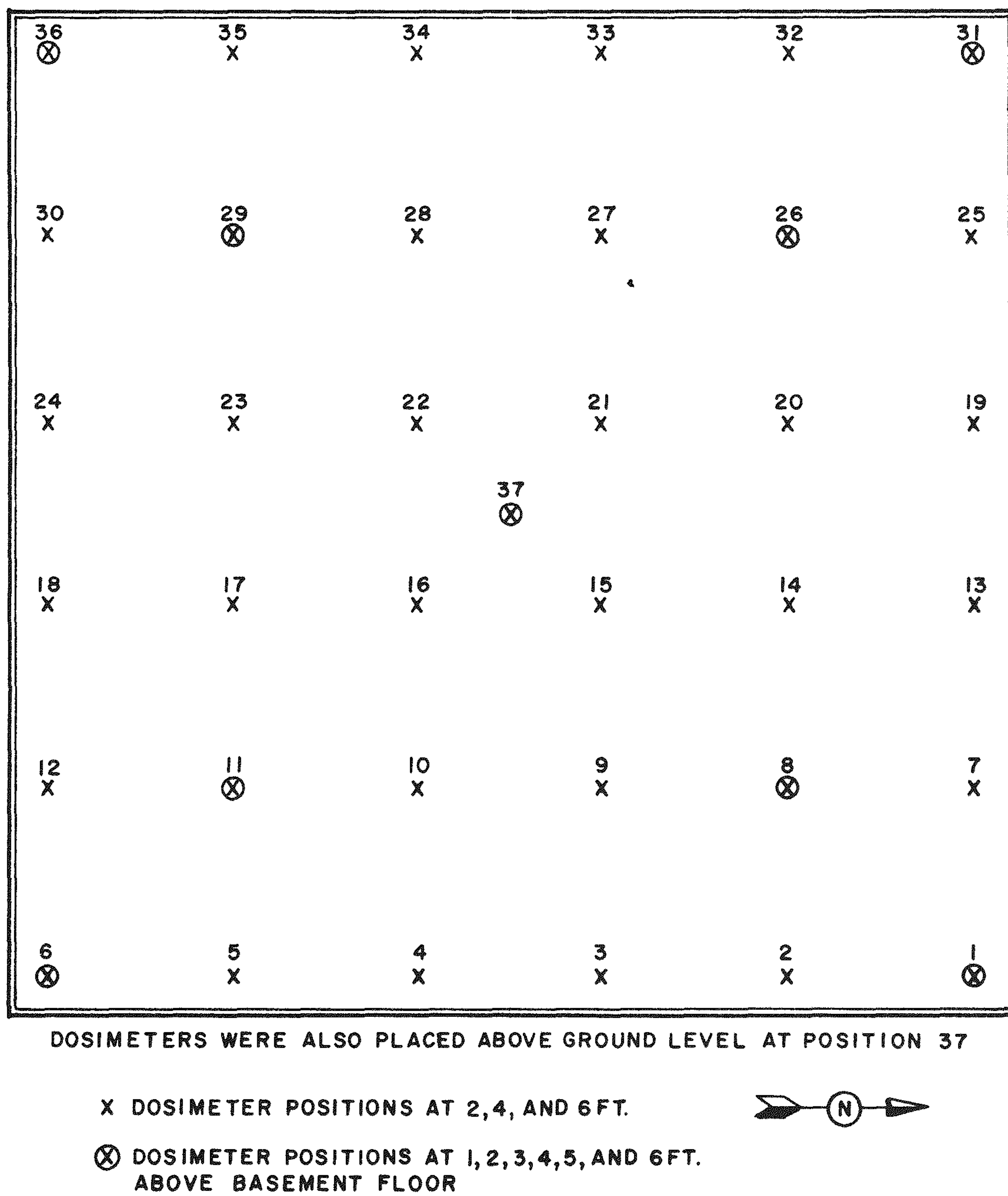


Fig. 3.1—Floor plan of the basement of the Butler building showing dosimeter positions.

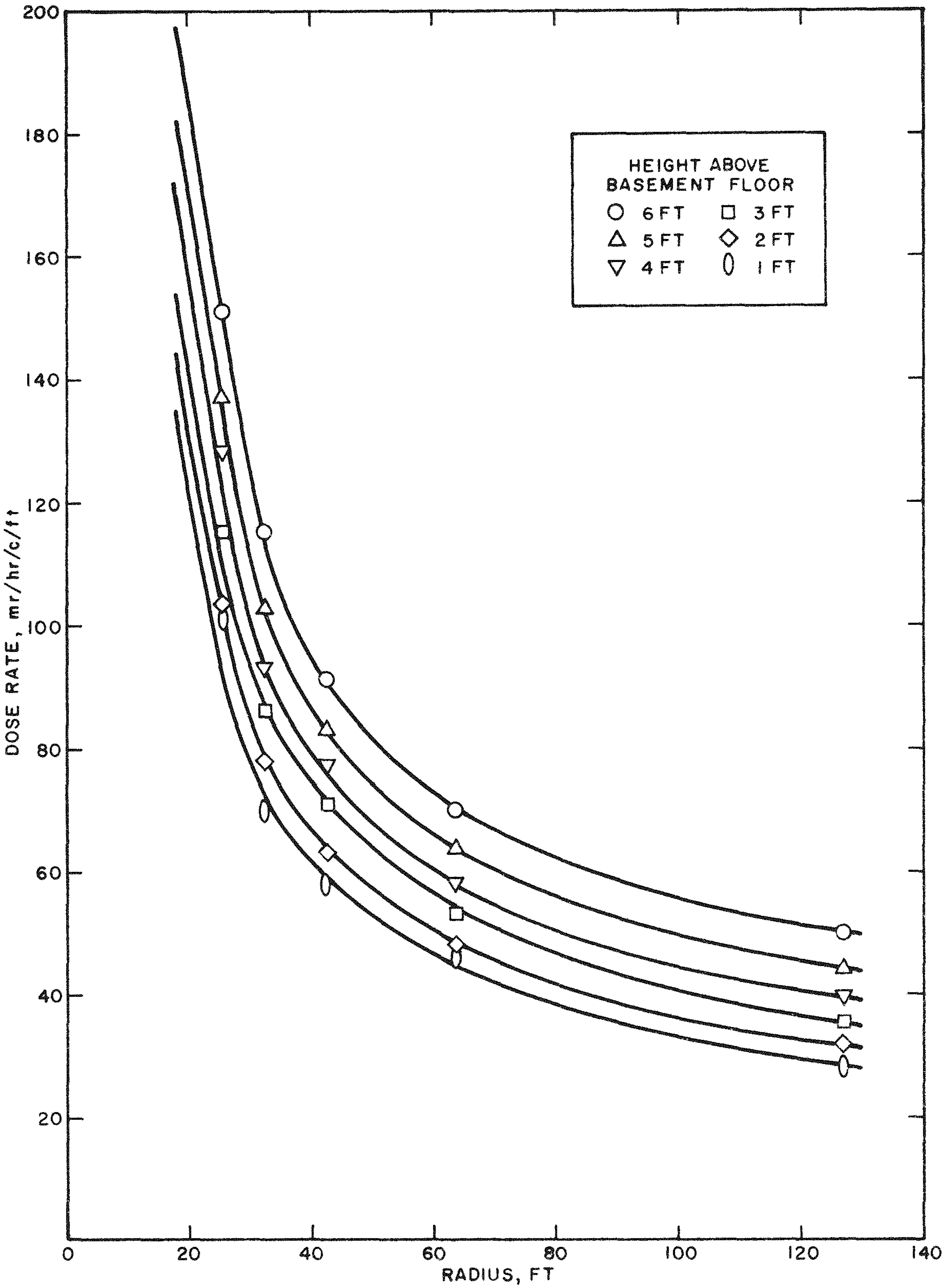


Fig. 3.2—Normalized dose rate from ring sources in center of Butler building.

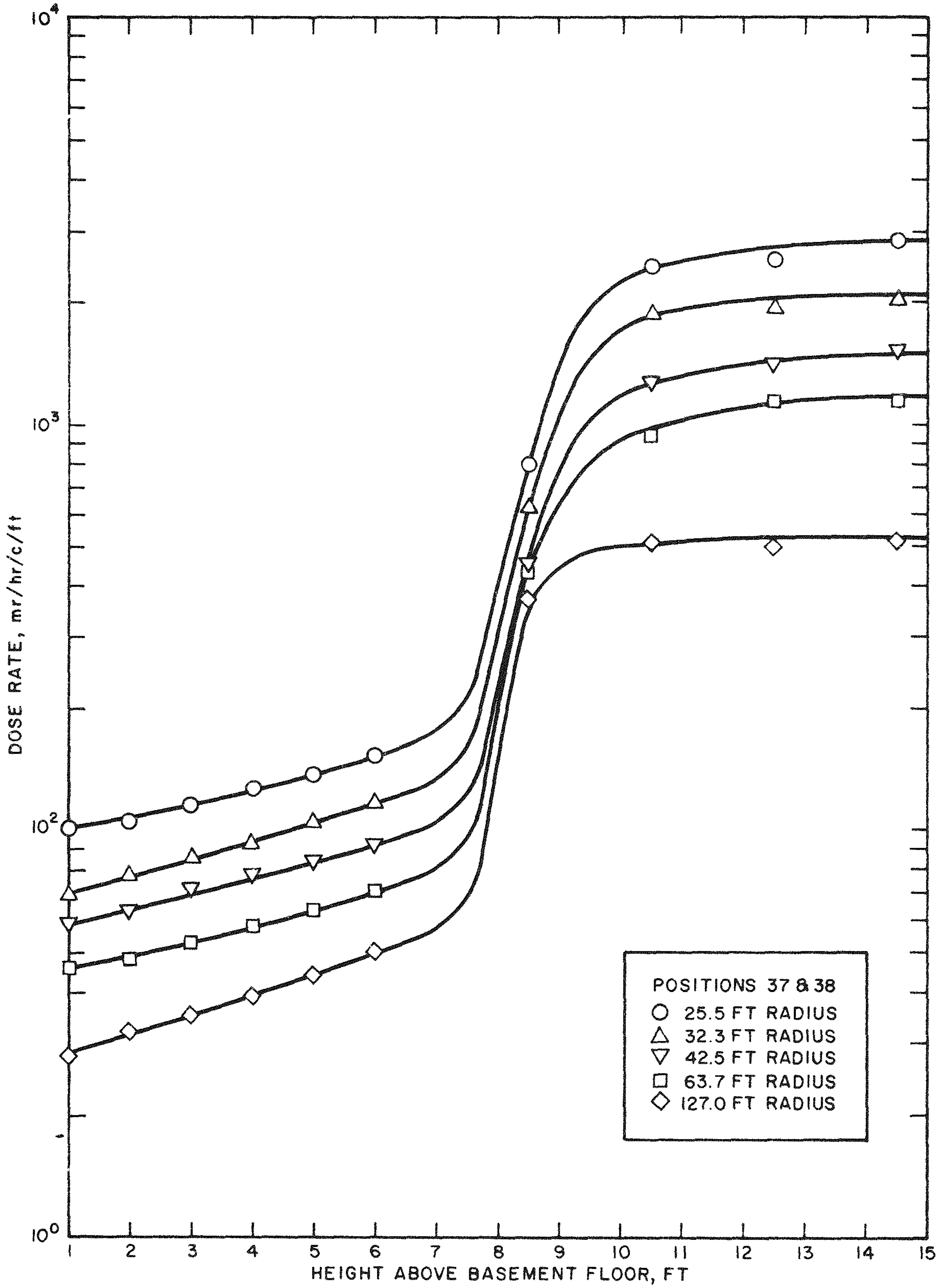


Fig. 3.3—Normalized dose rate from ring sources in center of Butler building (positions 37 and 38).

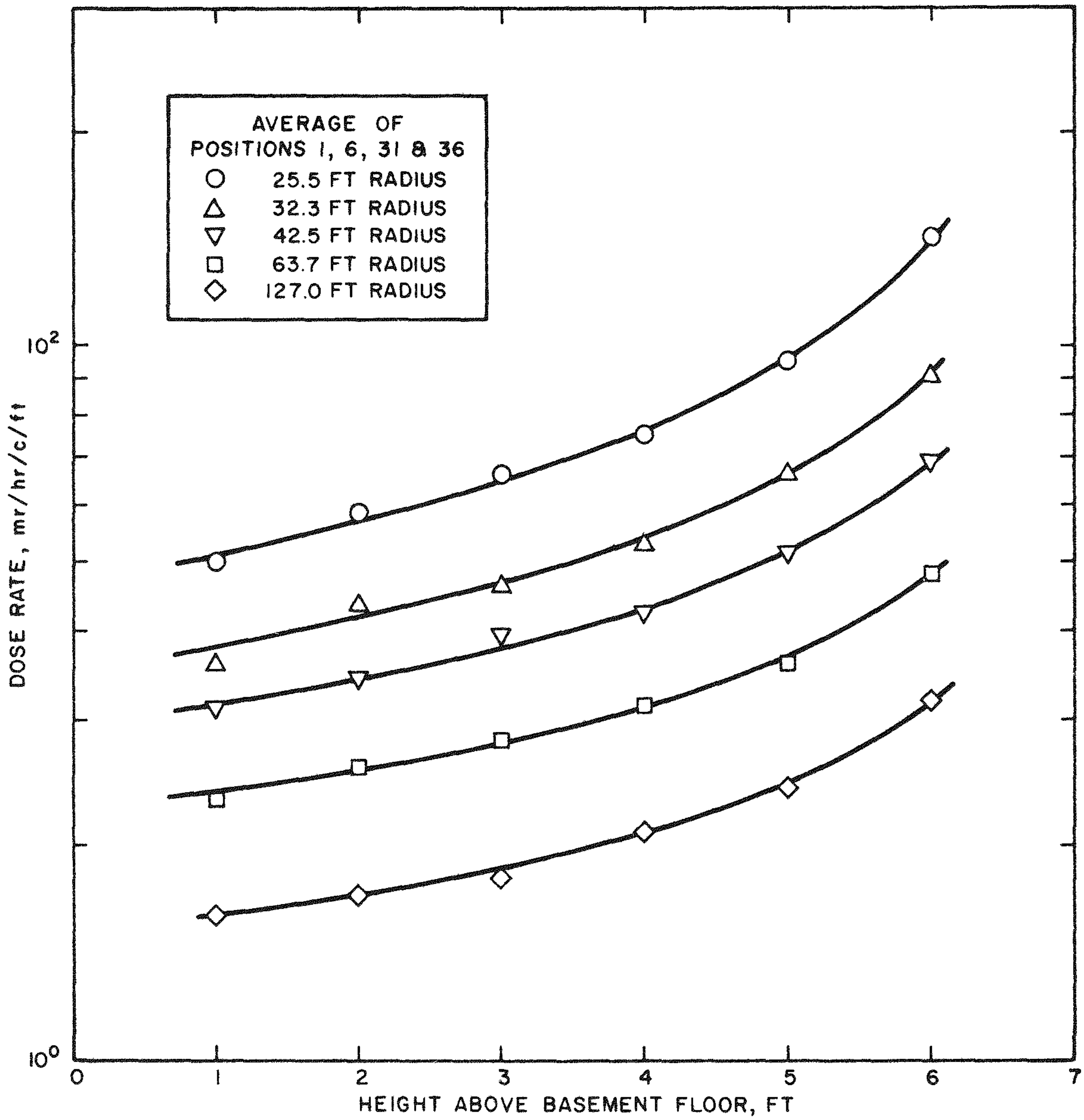


Fig. 3.4—Normalized dose rate from ring sources in Butler building (positions 1, 6, 31, and 36).

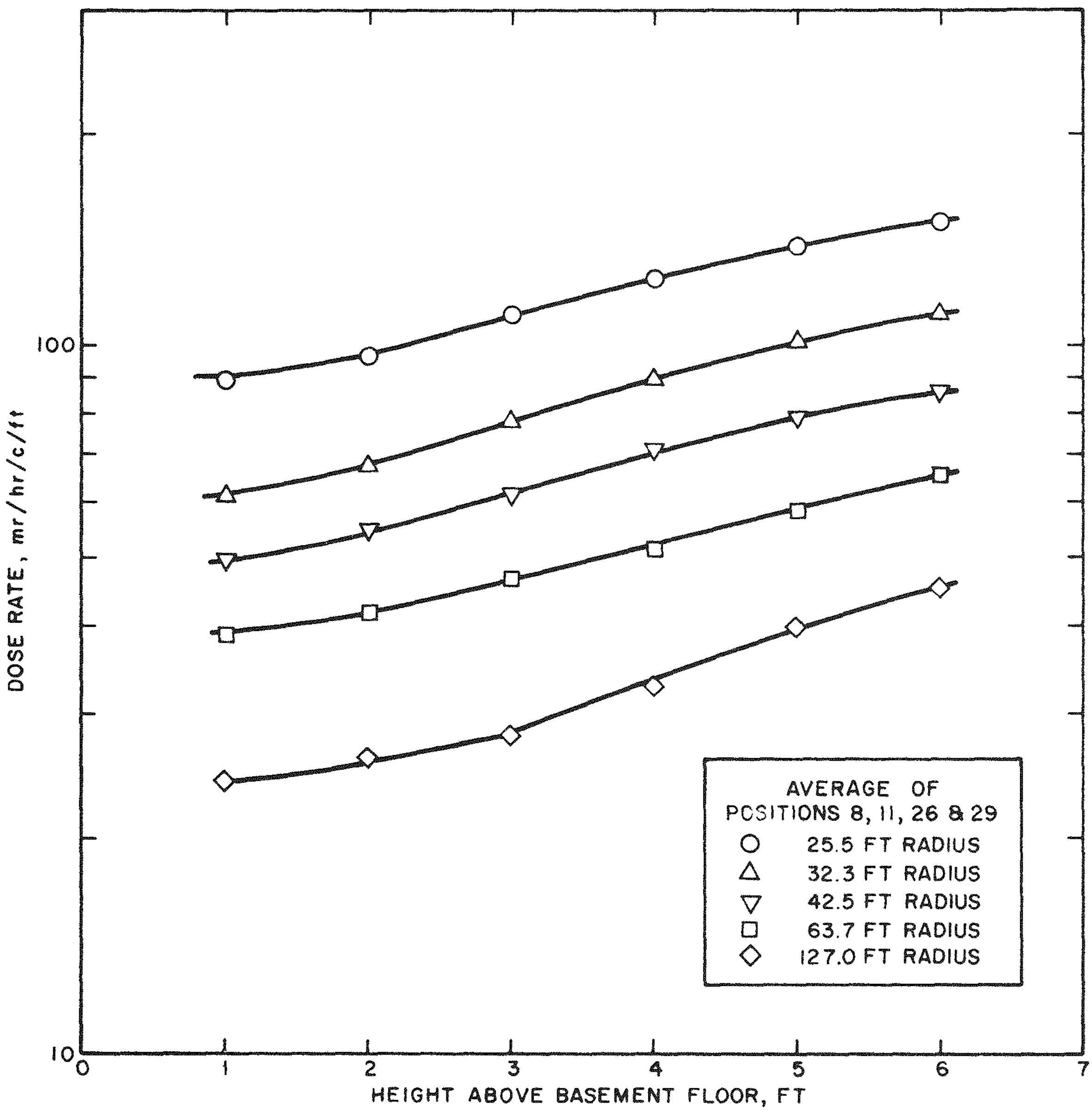


Fig. 3.5—Normalized dose rate from ring sources in Butler building (positions 8, 11, 26, and 29).

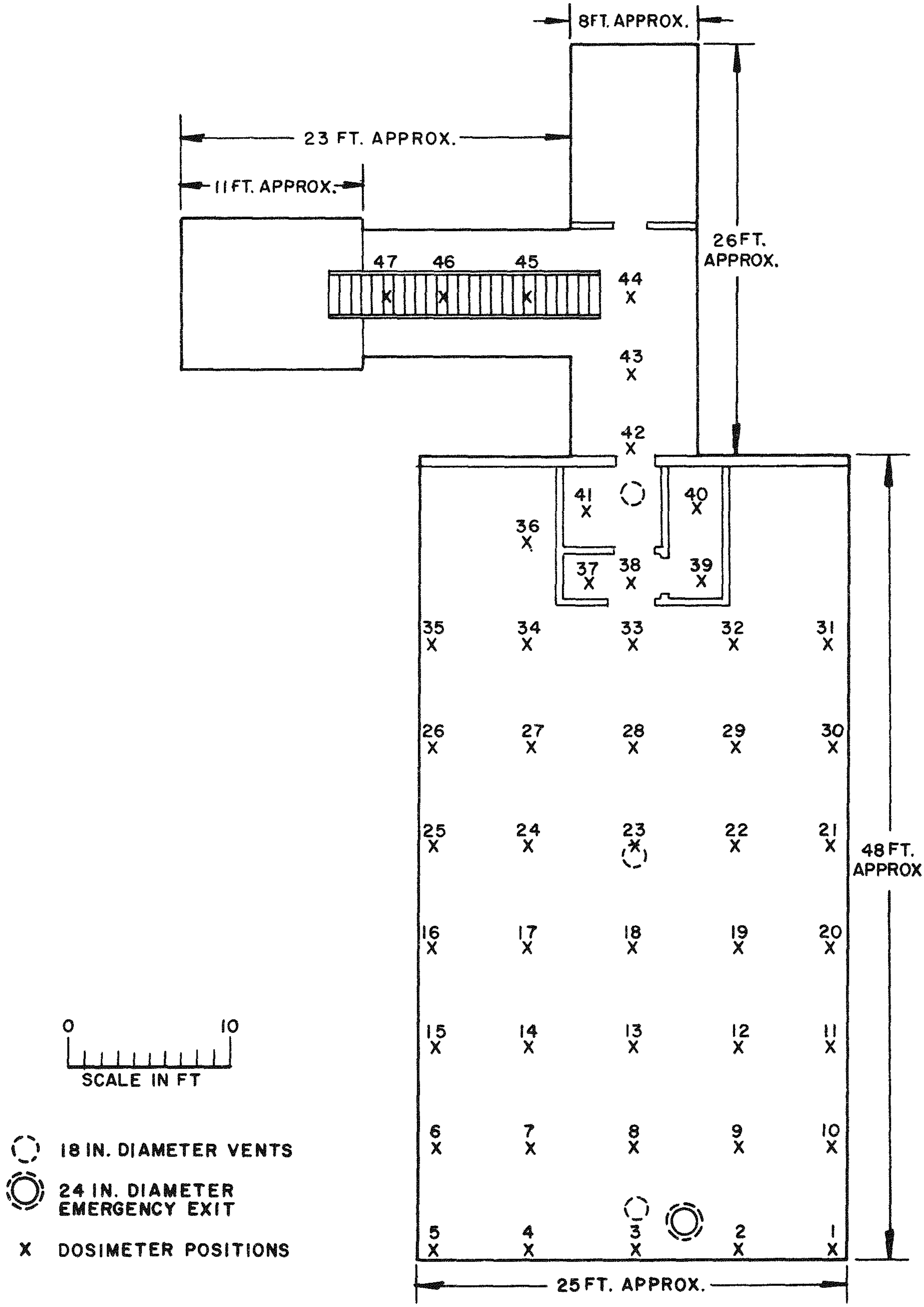


Fig. 3.6—Approximate plan of underground group shelter with dosimeter positions indicated.

Chapter 4

ANALYSIS AND CONCLUSIONS

4.1 GENERAL

The protection factor is the quantitative expression of the protective qualities of a structure. It is a number indicating the protective value of a structure, and it provides a measure of how much less the radiation level would be inside the structure than outside in an unprotected area. In technical terms it is the ratio of the exposure dose rate 3 ft above a smooth infinite plane, uniformly contaminated with radioactive material, to the dose rate at a specific point when the same source distribution is assumed.
Accordingly

$$\text{Protection factor} = D_\infty/D \qquad (4.1)$$

where D_∞ is the total infinite-plane dose rate and D is the dose rate at a specific point.

The total infinite-plane dose rate has been evaluated and estimated[1] to be 500 mr/hr for Co^{60} as the radioactive material distributed to a source density of 1 mc/sq ft.

The use of Co^{60} in simulating fallout radiation for shielding studies has been discussed.[2,3] The protection factors for radiation from fission products and from Co^{60} gamma radiation should compare quite closely at early times after a detonation.

To accurately measure a protection factor would require simulating fallout radiation on the ground surrounding the structure out to an infinite distance. Since this was impractical, simulation in these experiments was limited to the immediate vicinity of the structures where results would be most helpful in estimating protection factors. Contribution from areas not simulated was analytically estimated by theoretical calculations, and experimental data were used as guide lines when possible.

4.2 NORMALIZATION OF DATA

To evaluate the results properly, it was convenient to normalize all the experimental data from an exposure to a standard source density.

For the underground group shelter and the roof of the Butler building, the measurements were normalized to a standard area-source density (since an area source was simulated). After the dosimeter readings were corrected for background, air density, and calibration, they were normalized by multiplying the corrected readings (D_c in milliroentgens) by the total area (A in square feet over which the tubing was distributed) and dividing by the exposure time (T in hours) and by the source strength (S in millicuries). Thus

$$\text{Normalized dose rate (mr/hr/mc/square foot)} = \frac{D_c \times A}{T \times S}$$

The resulting dose rate at a particular point is the same as it would be if the same area were contaminated by Co^{60} to the source density of 1 mc/sq ft.

Ground measurements at the Butler building were made by simulating ring sources at particular radii from the center of the structure. These were normalized as follows:

$$\text{Normalized dose rate (mr/hr/curie/ft)} = \frac{D_c \times 2\pi r}{T \times S}$$

where r is the radius in feet and S is the source strength in curies.

4.3 THEORETICAL CALCULATIONS

To compare the experimental results with theoretical calculations and to aid in evaluating the contribution from areas not measured, calculations of the expected dose rates were made.

Calculations were made of the total radiation level at a height h above the center of a ring source of radius r and of the air-scattered radiation level bounded by the solid angle ω. The total normalized dose rate $D^{(1)}$ at point A in Fig. 4.1 is expressed in the form

$$D^{(1)}(h,r) = \frac{[SB(\mu_0 x)\ K(h,r)e^{-\mu_0 x}\ 2\pi r]}{x^2} \quad (4.2)$$

where S = a source-strength normalization factor at a unit distance (for Co^{60} it would be 14.53 r/hr at 1 ft from a point source of 1 curie)

$B(\mu_0 x)$ = the dose build-up factor for an isotropic point source in an infinite homogeneous medium

$= 1 + \mu_0 x(1.325e^{0.0314\mu_0 x} - 0.461e^{-0.244\mu_0 x})$, for a 1.28-Mev source in water (according to Berger[4])

K(h,r) = the boundary correction factor for the air-ground interface[4]

μ_0 = the narrow-beam attenuation coefficient of the source radiation. Its value is taken as 0.0019 ft^{-1} for NTS

$x = \sqrt{h^2 + r^2}$

For the ring sources used at the Butler building, Table 4.1 summarizes the information used to calculate the dose rate in the center of the ring source at a height of 7 ft above the ground.

In calculating the air-scattered component $D^{(2)}$ at point B of Fig. 4.1, the following equation is used

$$D^{(2)}(\omega,r) = \frac{\{Se^{-\mu_0 r}\ G(\omega)\ 2\pi r[B(\mu_0 r) - 1]\}}{r^2} \quad (4.3)$$

where $G(\omega)$ is a directional response function dependent on the solid angle ω. Equation 4.3 is the air-scattered component in a homogeneous medium bounded by an allowed cone of incidence pointed away from the source-detector plane. Directional response curves given in Figs. B.37 and B.39 of Spencer's report[3] were used to obtain values of $G(\omega)$. Table 4.2 gives values of $D^{(2)}(\omega,r)$ as a function of r and ω.

It is of interest now to compare the measured dose rate at a height 7 ft above the foundation in the center of the Butler building to the calculated dose rate at that point. The two sets of data are tabulated in Table 4.3. The reduction factor of the experimental data also indicated is presumably caused by absorption in the steel framework of the structure.

If it is assumed that the attenuating materials in the sides of the Butler building are all steel, then the effective mass thickness would be about 14 lb/sq ft.

Since the walls of the Butler building offered some attenuating material, some of the radiation reaching the detectors in the basement probably was from wall scattering (radiation originating on the ground outside and scattered in the walls of the structure). Therefore it is of interest to evaluate this component. For this evaluation it is assumed for convenience that the walls of the structure are concrete of a mass thickness of 14 lb/sq ft. From chart 7 of the Office of Civil Defense (OCD) Engineering Manual,[5] it is seen that the fraction of emergent radiation scattered in a wall barrier of 14 lb/sq ft mass thickness is 0.27.

The 2- by 6-in. wood-frame braces over the roof of the basement present an effective mass thickness of about 2.5 lb/sq ft with corresponding attenuation of about 0.70 (Spencer,[3] page 100) for both wall scatter and skyshine. The walls are assumed to present an attenuation of 0.68 for wall scatter and about 0.58 for skyshine.

Solid-angle fractions and directional response functions for wall-scattered radiation were found by the use of charts 3 and 5 of the OCD manual.[5] Use of the above-mentioned attenuation factors permitted calculation of the skyshine and wall-scattered components of the detector response in the center of the basement (Table 4.4). The results of the calculations are shown in Table 4.4, and they include a weighting and differencing of directional response functions according to the procedures in the OCD manual.[5] Also included is a correction factor of 1.2 to correct for radiation backscattered from the walls and floor of the basement as suggested by Spencer (page 56 of Ref. 3). Wall-scattered contribution includes a correction of 1.42 (shape factor) from chart 8 of the OCD manual.[5]

4.4 ESTIMATES OF THE PROTECTION FACTOR

To estimate the protection factors from experimental data at the Butler building, four different radiation contributions to the basement were considered. These were: (1) roof contribution, (2) contribution from ground contamination from the building out to a radius of 165 ft, (3) contribution from contamination beyond 165 ft and scattered in the walls of the structure, and (4) contribution from contamination beyond 165 ft and scattered in the air before reaching the wall.

The roof contribution was measured directly. Ground-contribution data were taken from ring sources at different radii. These data were plotted on a graph and integrated from a radius of 18 ft (effective radius to outer edge of structure) to a radius of 165 ft. Integration resulted in a normalized dose rate equivalent to the dose rate from uniform contamination caused by 1 mc/sq ft of Co^{60} covering the ground from the building out to a radius of 165 ft. The integration was done by the use of a digital computer. Several data points are plotted in Fig. 3.2; the integrated dose rates are presented in Table 4.5 along with contributions from ground contamination from beyond a radius of 165 ft.

To estimate the wall-scattered contribution from contamination beyond 165 ft, experimental data and information in Fig. 4.2 were used. Figure 4.2 was obtained by integration of information in Tables 4.1 and 4.2. Wall-scattered contribution is proportional to the gamma flux at the outside wall. The ratio of the flux from the contaminated area (out to 165 ft) to that beyond the contaminated area was estimated from Fig. 4.2 to be 2.8. The wall-scattered contribution (column 3, Table 4.5) was estimated by dividing the experimental data (column 2, Table 4.5) by this ratio. This estimation was probably somewhat high since ground-roughness effects were not considered.

The air-scattered contribution was calculated using the method in Sec. 4.3 and data from Fig. 4.2. This contribution appears in column 4 of Table 4.5.

The protection factors in column 8 of Table 4.5 were found by dividing 500 by the total contribution (Eq. 4.1). The total infinite-plane dose rate in Fig. 4.2 is about 530 mr/hr/mc/sq ft at an altitude corresponding to that at NTS. The value[1] at standard pressure (sea level) is more nearly 500 mr/hr/mc/sq ft.

In the case of the underground group shelter, fallout radiation was simulated on the ground directly above and immediately surrounding the shelter, whereas dosimeters measured the resulting radiation inside the structure.

Skyshine contribution from beyond the measurement area was considered to be insignificant in estimates of protection factors in the underground shelter. This contribution might slightly decrease the factors in the entranceway and near the vents but should not appreciably affect the factors inside the shelter proper.

Protection factors at positions in the underground shelter were found by dividing 500 mr/hr/mc/sq ft by the normalized experimental data, according to Eq. 4.1. The resulting protection factors appear in Table 4.6 and in Figs. 4.3 and 4.5.

4.5 COMPARISON OF MEASUREMENTS WITH DATA FROM FALLOUT

4.5.1 The Butler Building

During Operation Plumbbob the reinforced Butler building was exposed to fallout from shots Diablo and Shasta, and the resulting dose rates and fallout deposition inside and outside of the structure were measured with various instruments and techniques.[6] Protection factors and roof and ground contributions to the total dose rates at points within the structure were determined from the measurements. Protection factors were determined by the ratio of portable-survey-meter readings taken outside the structure at 3 ft, to those readings taken inside the structure.

Protection factors were plotted (Fig. 4.6) from the MRMU data and from data taken in fallout fields from shots Diablo and Shasta. The limitation of data reliability taken in the fallout fields is discussed in Ref. 6. Other factors that would influence the difference in protection factors from the two experimental methods are as follows:

1. Protection factors in the fallout situation were determined by the ratio of outside to inside dose rates. If the ground outside were perfectly smooth, the levels outside would be somewhat higher. Protection factors from MRMU data were determined from Eq. 4.1 in which a smooth plane is assumed for the infinite-plane dose rate.
2. The effective energy of the fallout spectrum at the time of measurements was probably lower than that from Co^{60}.
3. Nonuniformity or a variation in distribution of fallout outside, on the roof, or even in the basement of the structure undoubtedly affected the protection factors.

Reliability and limitations of the data (using the MRMU) are discussed in Sec. 4.6.

The protection factors from fallout data and MRMU data, shown in Fig. 4.6, are roughly within a factor of 2. The results are considered to be in good agreement in view of the limitations of the data and in view of the above-mentioned other factors that affected the differences.

4.5.2 Underground Group Shelter

Measurements were also made during the Diablo event of the dose rate at various positions inside the underground group shelter from fallout deposited on the ground outside.[7] Since Operation Plumbbob, the entranceway had been changed to a new location (see Appendix A of Ref. 7 and Figs. 1.5, 1.6, and 2.2 of this report).

The protection factors in the shelter proper, away from vents and openings, varied from 10,000 to 20,000 in a fallout situation (Fig. 4.4). The protection factors near vents varied from 2000 to 5000. Protection factors from MRMU data are presented in Fig. 4.5 and are seen to be in excellent agreement with those in Ref. 7.

It was presumed that the thickness of the earth cover was the same for the two sets of measurements. Fallout data were taken at H + 100 min and at H + 5½ hr. At these early times the penetration of fallout gamma rays through thick shields is comparable to that from Co^{60} (Fig. 26.6, Spencer[3]). For these reasons the agreement was expected to be good.

4.6 COMPARISON OF MEASUREMENTS WITH CALCULATIONS

Because of the limitations of comparing data from the MRMU experiment and from fallout at the Butler building, as previously mentioned, experimental data were compared to theoretical calculations. These calculations were developed and presented in Sec. 4.3.

Comparisons between experimental data and theoretical calculations are shown in Table 4.4 and in Fig. 4.7. The experimental data are within 20% of the calculations at the 1-ft level. The variation at the 6-ft level, however, is as much as a factor of 2.

4.6.1 Factors Influencing Experimental Data

Several factors might have influenced the magnitude of the experimental data. A different source strength was used for the 25.5-ft-radius measurement than for the other exposures. Variations in source calibration might have been as much as 10%.

Low-range ionization chambers (10 mr) were used for the 127-ft-radius measurement. High-range chambers (200 mr) were used for all other measurements. The calibration, energy, and angular response of these chambers are discussed in Appendix A. Tin sleeves were not used with the high-range chambers.

Errors in timing, in temperature and pressure determinations, or in physical measuring of distances might have occurred. Also some rocks or clods of dirt might have obstructed portions of the tubing for some of the measurements.

4.6.2 Factors Influencing Theoretical Calculations

The wood frames over the basement were assumed to have a mass thickness of 2.5 lb/sq ft spread evenly over the basement. Actually the data were taken directly under the center beam.

In addition, the steel frames in the walls were assumed to have a mass thickness of 14 lb/sq ft spread evenly in the walls. In Ref. 6 the mass thickness in the walls was estimated to be equivalent to 0.5 cm of iron (8 lb/sq ft), corresponding to an attenuation of 0.81. If this were true, the fraction of emergent radiation scattered in the wall would be about 0.18 rather than 0.27. This would reduce the wall-scattered contribution considerably.

The value of the air-ground interface correction factor at short distances is not well defined.[4] Experimental data by Rexroad[1] show that air-ground interface correction factors at short distances (15 to 200 ft) may be overestimated.

4.6.3 Comparison

When the preceding discussion is taken into account, the magnitudes of experimental data and theoretical calculations are considered to be in satisfactory agreement.

It is of interest to compare the slopes of the curves in Fig. 4.7. The experimental data appear to be more isotropic than the theoretical calculations.

Protection factors were calculated for points in the center of the structure by the use of the OCD manual,[5] assuming that the walls and roof present a mass thickness of 14 lb/sq ft. The values of the protection factors are plotted in Fig. 4.8, along with the protection factors based on experimental data.

The calculation of the roof contribution was expected to be somewhat higher than the data because of the assumption that the roof was flat and existed at the level of the eaves. Calculation of the ground contribution was also expected to be higher than the data.

The protection factors as estimated by the OCD manual and by using MRMU experimental data are within a factor of 1.5.

4.7 SUMMARY

Experimental measurements using the MRMU (equipment discussed in Appendix A) were made within a lightly constructed building with a basement and in an underground group shelter. These measurements were then compared with data taken during an actual fallout situation.

It had been generally assumed that the MRMU system simulated a finite, idealized fallout field for a variety of shielding studies; an idealized fallout field is defined as one in which the fallout is uniformly distributed on a smooth plane and the energy spectrum corresponds to a 1-hr fission spectrum. This report gives a comparison of data taken from the MRMU method of simulation with data taken in an actual fallout field.

Protection factors from fallout data and MRMU data at the basement structure were roughly within a factor of 2. This was rather good when the limitations of the two sets of data and other factors affecting the differences were considered. Comparisons between protection factors from fallout data and MRMU data at the underground group shelter were excellent.

Theoretical calculations were also made of radiation entering the basement structure. The magnitude of the experimental data and the calculations appear to be in satisfactory agreement. However, experimental data indicate that the air-scattered and wall-scattered radiation may be less directional than calculations predict.

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4. M. J. Berger, Calculation of Energy Dissipation by Gamma Radiation near the Interface Between Two Media, *J. Appl. Phys., 28*(12): 1502-1508(1957).
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6. A. J. Breslin, P. Loysen, and M. S. Weinstein, *Protection Against Fallout Radiation in a Simple Structure,* Project 32.1, Operation Plumbbob Report WT-1462 (in press).
7. W. E. Strope, *Evaluation of Countermeasure System Components and Operational Procedures,* USAEC Report WT-1464, Naval Radiological Defense Laboratory, Sept. 15, 1959.

TABLE 4.1—DOSE RATE AT 7 FT ABOVE GROUND, FROM RING SOURCES*

Radius, ft	$\mu_0 x$	$B(\mu_0 x)$	$K(\sim 0,r)$	$D^{(1)}(h,r)$, mr/hr/curie/ft
25.5	0.0502	1.0438	1.15	3810
32.3	0.0629	1.0549	1.16	3100
42.5	0.0819	1.0719	1.175	2430
63.7	0.1218	1.1075	1.175	1637
127	0.2413	1.2173	1.100	756
200	0.3800	1.3500	1.020	430
300	0.5700	1.5402	0.930	246.1
500	0.9500	1.9495	0.815	112.2
700	1.3300	2.3942	0.732	61.25
1000	1.9000	3.1214	0.640	27.27
2000	3.8000	6.30	0.460	2.955
5000	9.5000	17.75	0.220	0.0053

*See Eq. 4.2.

TABLE 4.2—AIR-SCATTERED GAMMA RADIATION LEVEL, FROM RING SOURCES

Radius, ft	$D^{(2)}(\omega,r)$, mr/hr/curie/ft, for the indicated values of ω						
	$\omega = 3.96$*	$\omega = 4.27$*	$\omega = 4.58$*	$\omega = 4.90$*	$\omega = 5.27$*	$\omega = 5.72$*	$\omega = 6.09$*
25.5	25.0	28.4	32.3	36.9	42.9	52.2	62.7
32.3	25.0	28.3	32.2	36.9	42.8	52.1	62.6
42.5	25.0	28.4	32.3	36.9	42.9	52.2	62.7
63.7	24.4	27.6	31.3	35.8	41.6	50.7	60.9
127	22.1	25.1	28.4	32.5	37.8	46.0	55.2
200	19.7	22.3	25.3	29.1	33.7	41.0	49.2
300	16.7	19.0	21.5	24.6	28.6	34.8	41.8
500	12.1	13.7	15.5	17.8	20.7	25.1	30.2
700	8.77	9.94	10.9	12.9	15.0	18.3	21.9
1000	5.22	5.89	6.72	7.68	8.93	10.8	13.0
2000	0.973	1.10	1.25	1.43	1.66	2.03	2.43

*Values of ω are given in steradians corresponding to distances above basement floor of 1 to 7 ft in the center of the building (see Eq. 4.3).

TABLE 4.3—DOSE RATE AT 7 FT ABOVE GROUND, FROM RING SOURCES

Radius, ft	Dose rate, mr/hr/curie/ft		
	Experimental	Theoretical	Attenuation
25.5	2840	3810	0.747
32.3	2050	3100	0.661
42.5	1500	2430	0.617
63.7	1130	1637	0.691
127	520	756	0.688
		Average	0.681

TABLE 4.4—CALCULATED SKYSHINE AND WALL SCATTER COMPONENTS IN CENTER OF BASEMENT OF BUTLER BUILDING

Radius, ft	Height above floor, ft	Dose rate, mr/hr/curie/ft			
		Skyshine	Wall scatter	Total	Data
25.5	1	8.9	95.5	104	101
	2	10.2	114	124	103
	3	11.5	130	142	115
	4	13.2	150	163	128
	5	15.3	187	202	137
	6	18.5	237	255	151
32.3	1	8.9	74.6	84	70
	2	10.0	88.9	99	78
	3	11.4	102	113	86
	4	13.2	117	130	93
	5	15.2	145	160	103
	6	18.5	185	203	115
42.5	1	8.9	61.2	70	58
	2	10.2	74.0	84	63
	3	11.5	83.6	95	71
	4	13.2	96.5	110	77
	5	15.3	120	135	83
	6	18.5	152	170	91
63.7	1	8.7	41.2	50	46
	2	9.8	49.1	59	48
	3	11.1	56.2	67	53
	4	12.7	64.9	77	58
	5	14.8	80.6	95	63
	6	18.0	102	120	70
127	1	7.9	19.0	27	28
	2	8.9	22.7	32	32
	3	10.2	26.0	36	35
	4	11.5	30.0	42	39
	5	13.5	37.2	51	44
	6	16.4	47.2	64	50

TABLE 4.5—SUMMARY OF EXPERIMENTAL RESULTS IN THE BUTLER BUILDING

	Ground contribution, mr/hr/mc/sq ft						
Position	Data at <165 ft	Wall scatter at >165 ft	Skyshine at >165 ft	Ground (total)	Roof contribution, mr/hr/mc/sq ft	Total dose rate, mr/hr/mc/sq ft	Protection factor
				1-ft Height			
1	3.4	1.2	1.6	6.2	19	25	20
6	3.5	1.2	1.6	6.3	17	23	22
8	5.5	2.0	2.8	10.3	25	35	14
11	5.6	2.0	2.8	10.4	24	34	15
26	5.5	2.0	2.8	10.3	24	34	15
29	5.5	2.0	2.8	10.3	22	32	16
31	3.5	1.2	1.6	6.3	17	23	22
36	3.4	1.2	1.6	6.2	17	23	22
37	6.4	2.3	3.6	12.3	28	40	12
38	61	19		80	46	126	4
				2-ft Height			
1	3.8	1.4	1.7	6.9	20	27	19
2	4.8	1.7	2.2	8.7	23	32	16
3	5.0	1.8	2.5	9.3	23	32	16
4	5.0	1.8	2.5	9.3	23	32	16
5	4.8	1.7	2.2	8.7	22	31	16
6	3.6	1.3	1.7	6.6	17	24	21
7	5.0	1.8	2.2	9.0	22	31	16
8	6.0	2.1	3.1	11.2	26	37	14
9	6.4	2.3	3.5	12.2	26	38	13
10	6.3	2.2	3.5	12.0	26	38	13
11	6.2	2.2	3.1	11.5	25	37	14
12	5.0	1.8	2.2	9.0	21	30	17
13	4.9	1.8	2.5	9.2	22	31	16
14	6.4	2.3	3.5	12.2	28	40	12
15	6.9	2.5	4.0	13.4	28	41	12
16	6.9	2.5	4.0	13.4	28	41	12
17	6.3	2.3	3.5	12.1	27	39	13
18	5.1	1.8	2.5	9.4	23	32	16
19	4.9	1.8	2.5	9.2	22	31	16
20	6.2	2.2	3.5	11.9	26	38	13
21	6.9	2.5	4.0	13.4	28	41	12
22	6.6	2.4	4.0	13.0	27	40	12
23	6.3	2.3	3.5	12.1	27	39	13
24	4.9	1.8	2.5	9.2	23	32	16
25	4.6	1.6	2.2	8.4	20	28	18
26	5.6	2.0	3.1	10.7	23	34	15
27	6.7	2.4	3.5	12.6	27	40	12
28	6.3	2.3	3.5	12.1	25	37	14
29	6.1	2.2	3.1	11.4	25	36	14
30	4.6	1.6	2.2	8.4	20	28	18
31	3.7	1.3	1.7	6.7	18	25	20
32	4.7	1.7	2.2	8.6	22	31	16
33	5.0	1.8	2.5	9.3	24	33	15
34	5.1	1.8	2.5	9.4	24	33	15
35	4.7	1.7	2.2	8.6	23	32	16

(Table continues on following page.)

TABLE 4.5 — (Continued)

Position	Ground contribution, mr/hr/mc/sq ft: Data at < 165 ft	Wall scatter at > 165 ft	Skyshine at > 165 ft	Ground (total)	Roof contribution, mr/hr/mc/sq ft	Total dose rate, mr/hr/mc/sq ft	Protection factor
36	3.7	1.3	1.7	6.7	19	26	19
37	7.0	2.5	4.1	13.6	28	42	12
				3-ft Height			
1	4.2	1.5	1.9	7.6	20	27	19
6	4.1	1.5	1.9	7.5	18	26	19
8	6.3	2.3	3.7	12.3	27	39	13
11	6.4	2.3	3.7	12.4	27	39	13
26	6.5	2.3	3.7	12.5	27	40	12
29	6.6	2.4	3.7	12.7	26	39	13
31	4.1	1.5	1.9	7.5	20	28	18
36	4.2	1.5	1.9	7.6	20	28	18
37	7.6	2.7	4.7	15.0	30	45	11
38*	133	42		175	58	233	2.1
				4-ft Height			
1	4.7	1.7	2.1	8.5	22	31	16
2	5.9	2.1	3.0	11.0	25	36	14
3	6.0	2.1	3.3	11.4	26	37	14
4	5.9	2.1	3.3	11.3	24	35	14
5	5.9	2.1	3.0	11.0	24	35	14
6	4.7	1.7	2.1	8.5	19	28	18
7	5.9	2.1	3.0	11.0	24	35	14
8	7.6	2.7	4.4	14.7	29	44	11
9	7.7	2.8	4.9	15.4	29	44	11
10	7.5	2.7	4.9	15.1	28	43	12
11	7.7	2.8	4.4	14.9	28	43	12
12	6.2	2.2	3.0	11.4	25	36	14
13	6.1	2.2	3.3	11.6	25	37	14
14	7.9	2.8	4.9	15.6	30	46	11
15	8.2	2.9	5.3	16.4	31	47	11
16	7.9	2.8	5.3	16.0	29	45	11
17	7.8	2.8	4.9	15.5	31	47	11
18	6.3	2.3	3.3	11.9	26	38	13
19	6.4	2.3	3.3	12.0	26	38	13
20	7.9	2.8	4.9	15.6	31	47	11
21	8.5	3.0	5.3	16.8	30	47	11
22	8.2	2.9	5.3	16.4	30	46	11
23	8.1	2.9	4.9	15.9	30	46	11
24	6.6	2.4	3.3	12.3	26	38	13
25	5.8	2.1	3.0	10.9	25	36	14
26	7.6	2.7	4.4	14.7	28	43	12
27	8.0	2.9	4.9	15.8	29	45	11
28	7.9	2.8	4.9	15.6	29	45	11
29	7.5	2.7	4.4	14.6	28	43	12
30	6.1	2.2	3.0	11.3	25	36	14

(Table continues on following page.)

TABLE 4.5 — (Continued)

Position	Ground contribution, mr/hr/mc/sq ft: Data at < 165 ft	Wall scatter at > 165 ft	Skyshine at > 165 ft	Ground (total)	Roof contribution, mr/hr/mc/sq ft	Total dose rate, mr/hr/mc/sq ft	Protection factor
31	4.7	1.7	2.1	8.5	21	30	17
32	5.8	2.1	3.0	10.9	25	36	14
33	6.2	2.2	3.3	11.7	25	37	14
34	6.3	2.2	3.3	11.8	25	37	14
35	5.9	2.1	3.0	11.0	25	36	14
36	4.8	1.7	2.1	8.6	23	32	16
37	8.4	3.0	5.5	16.9	33	50	10
				5-ft Height			
1	5.7	2.0	2.5	10.2	24	34	15
6	5.7	2.0	2.5	10.2	22	32	16
8	8.9	3.2	5.3	17.4	31	48	10
11	8.9	3.2	5.3	17.4	29	46	11
26	8.7	3.1	5.3	17.1	29	46	11
29	8.9	3.2	5.3	17.4	29	46	11
31	5.4	1.9	2.5	9.8	23	33	15
36	5.8	2.1	2.5	10.4	23	33	15
37	9.3	3.3	6.2	18.8	36	55	9.1
38*	141	44		185	(73)†	258	1.9
				6-ft Height			
1	8.0	2.9	3.2	14.1	24	38	13
2	8.8	3.1	4.5	16.4	30	46	11
3	8.5	3.0	4.7	16.2	31	47	11
4	8.2	2.9	4.7	15.8	28	44	11
5	8.4	3.0	4.5	15.9	28	44	11
6	7.7	2.8	3.2	13.7	23	37	14
7	8.8	3.1	4.5	16.4	29	45	11
8	10.0	3.6	6.6	20.2	36	56	8.9
9	9.9	3.5	7.0	20.4	37	57	8.8
10	9.2	3.3	7.0	19.5	35	55	9.1
11	9.9	3.5	6.6	20.0	34	54	9.3
12	8.7	3.1	4.5	16.3	29	45	11
13	8.1	2.9	4.7	15.6	27	43	12
14	10.3	3.7	7.0	21.0	30	51	9.8
15	10.1	3.6	7.4	21.1	35	56	8.9
16	9.9	3.5	7.4	20.8	34	55	9.1
17	10.4	3.7	7.0	21.1	32	53	9.4
18	9.0	3.2	4.7	16.9	28	45	11
19	8.2	2.9	4.7	15.8	25	41	12
20	10.6	3.8	7.0	21.4	33	54	9.3
21	9.9	3.5	7.4	20.8	33	54	9.3
22	10.2	3.6	7.4	21.2	34	55	9.1
23	10.4	3.7	7.0	21.1	32	53	9.4
24	8.3	3.0	4.7	16.0	24	40	12
25	8.4	3.0	4.5	15.9	28	44	11

(Table continues on following page.)

TABLE 4.5 — (Continued)

Position	Ground contribution, mr/hr/mc/sq ft				Roof contribution, mr/hr/mc/sq ft	Total dose rate, mr/hr/mc/sq ft	Protection factor
	Data at < 165 ft	Wall scatter at > 165 ft	Skyshine at > 165 ft	Ground (total)			
26	9.6	3.4	6.6	19.6	32	52	9.6
27	9.6	3.4	7.0	20.0	35	55	9.1
28	9.8	3.5	7.0	20.3	36	56	8.9
29	9.7	3.5	6.6	19.8	32	52	9.6
30	8.8	3.1	4.5	16.4	28	44	11
31	7.3	2.6	3.2	13.1	25	38	13
32	8.6	3.1	4.5	16.2	29	45	11
33	8.9	3.2	4.7	16.8	31	48	10
34	8.5	3.0	4.7	16.2	31	47	11
35	8.4	3.0	4.5	15.9	28	44	11
36	8.0	2.9	3.2	14.1	25	39	13
37	10.5	3.8	7.4	21.7	37	59	8.5
				7-ft Height			
38*	151	47		198	(90)†	288	1.7

* Position 38 was in the center of the building. Heights refer to distances above the foundation.
† Data estimated by extrapolation.

TABLE 4.6 — PROTECTION FACTORS* IN THE UNDERGROUND SHELTER

Position	Height, ft							Position	Height, ft						
	1	3	4	5	6	7	10		1	3	4	5	6	7	10
1	50	60						25	60	96					
2	11	8		5				26	80	120					
3								27	42	42					
4	25	27		31				28	14	14		18			
5	68	80						29	42	42		53			
6	60	68						30	96	96					
7	25	25		31				31	120	150					
8	6	7	7	8		8		32	96	120		120			
9	16	18		21				33	68	50		96			
10	42	53						34	60	68		120			
11	53	68						35	96	120					
12	28	29		33				36	96	96		150			
13	18	18		20		18		37	80	28		240			
14	31	33		42				38	68	80		150			240
15	68	80						39	80	120		240			
16	42	80						40	96	150		150			
17	26	38		42				41	80	96		500			
18	10	10		12		13		42	80	150		240			
19	26	26		33				43	19	24		53			
20	60	68						44							
21	68	68						45							
22	23	28		28				46			0.560		0.450		
23			2.3		1.4			47			0.360		0.310		
24	28	29		33											

*Multiply by 1000.

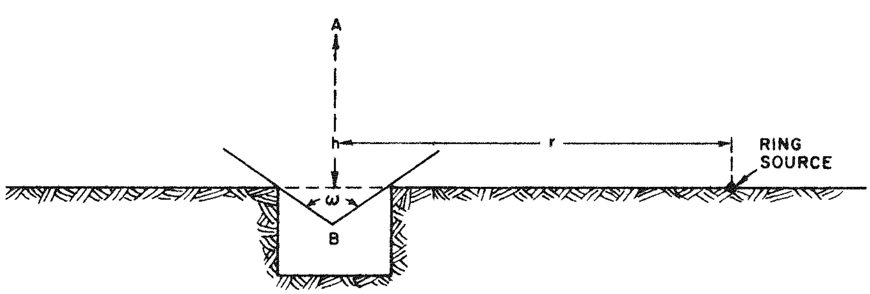


Fig. 4.1 — Schematization.

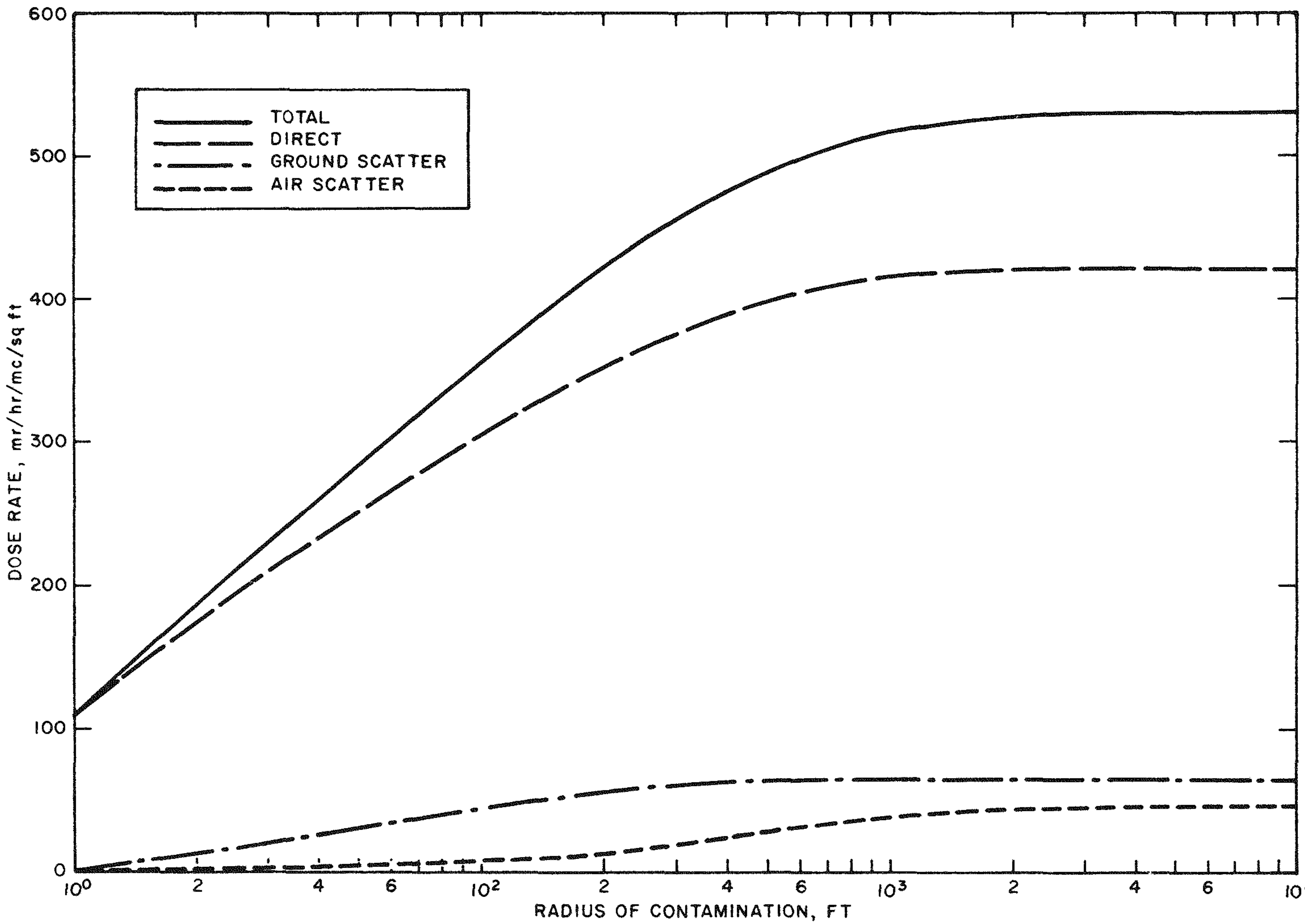


Fig. 4.2—Dose rate 3 ft above the center of the Co^{60}-contaminated circular area at the altitude of the Nevada Test Site.

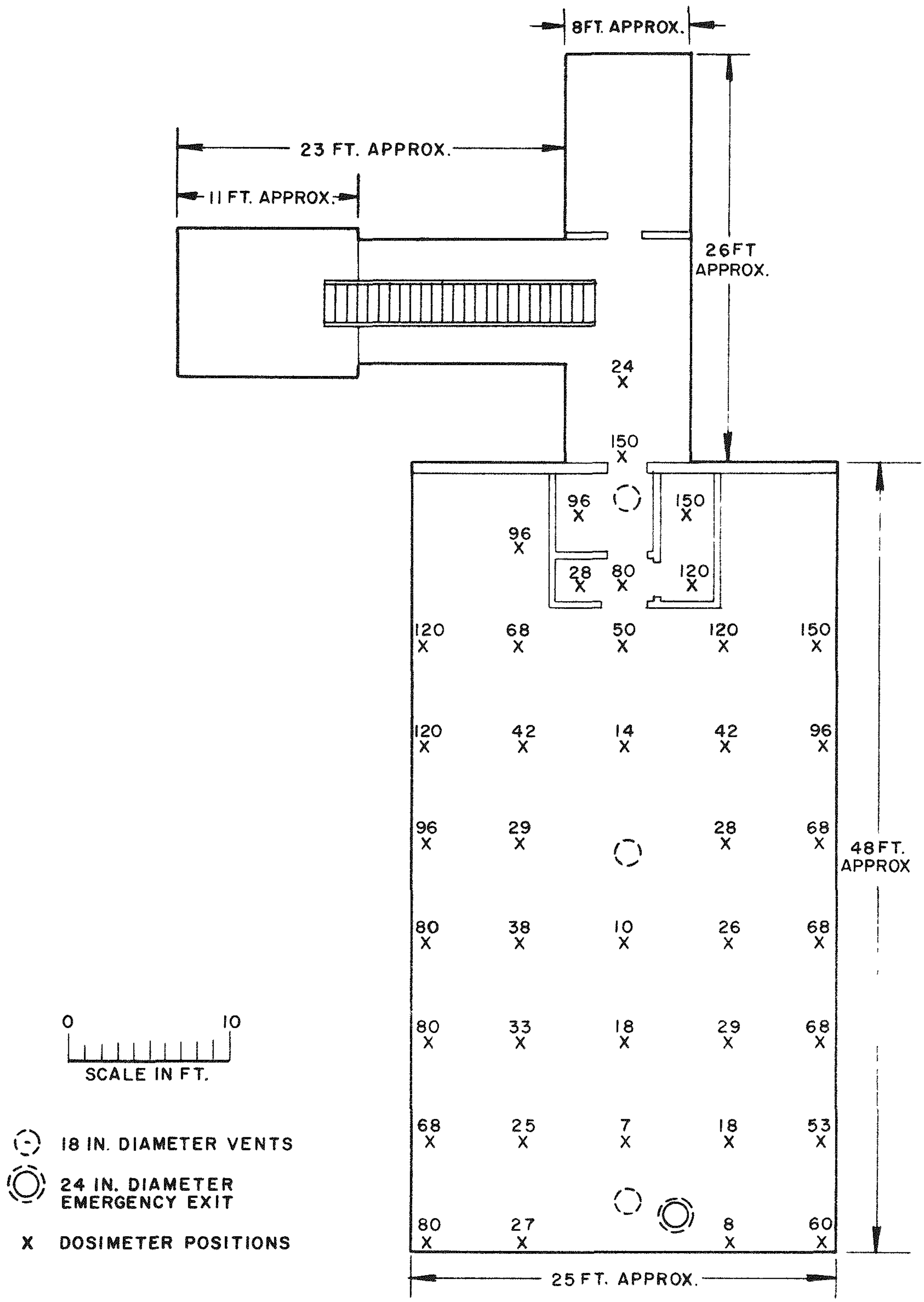


Fig. 4.3 — Approximate plan of underground group shelter showing protection factors (multiply by 1000) at 3 ft.

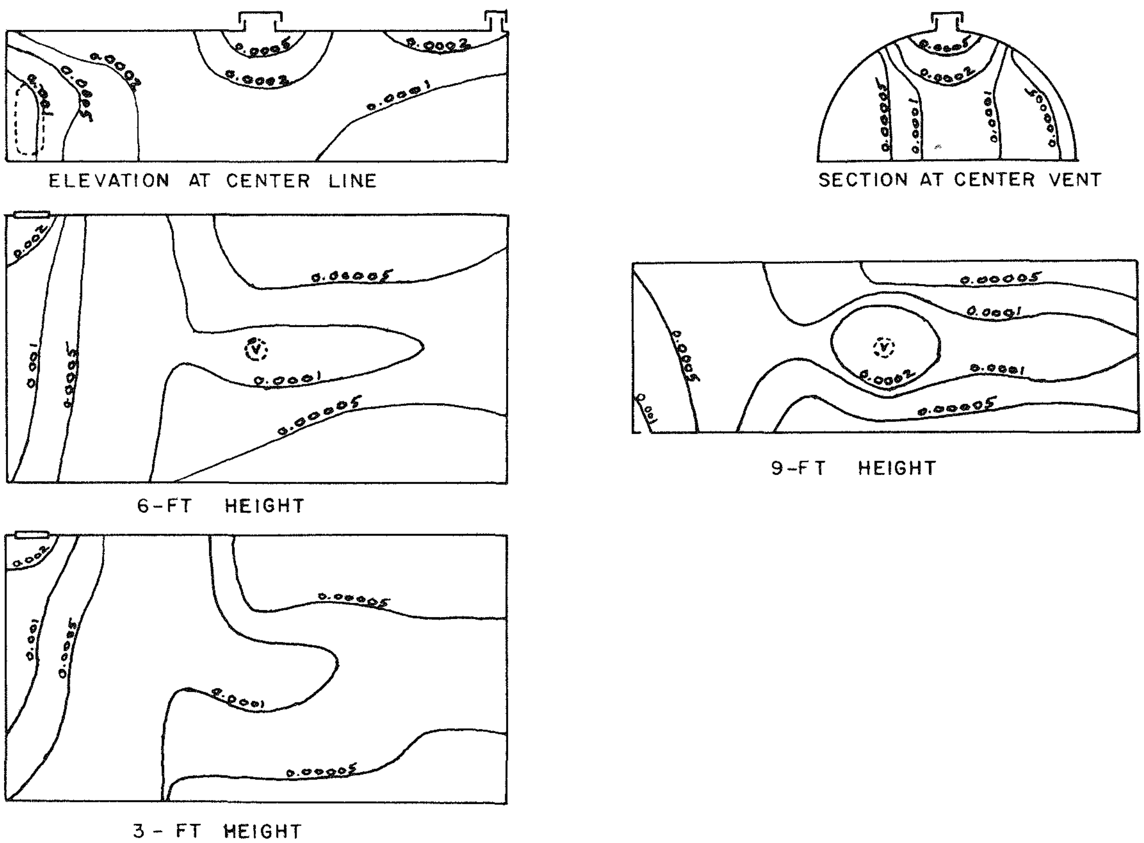


Fig. 4.4—Residual-number contours for first interior survey, shot Diablo. (Reproduced from Fig. 3.18 in WT-1464.)

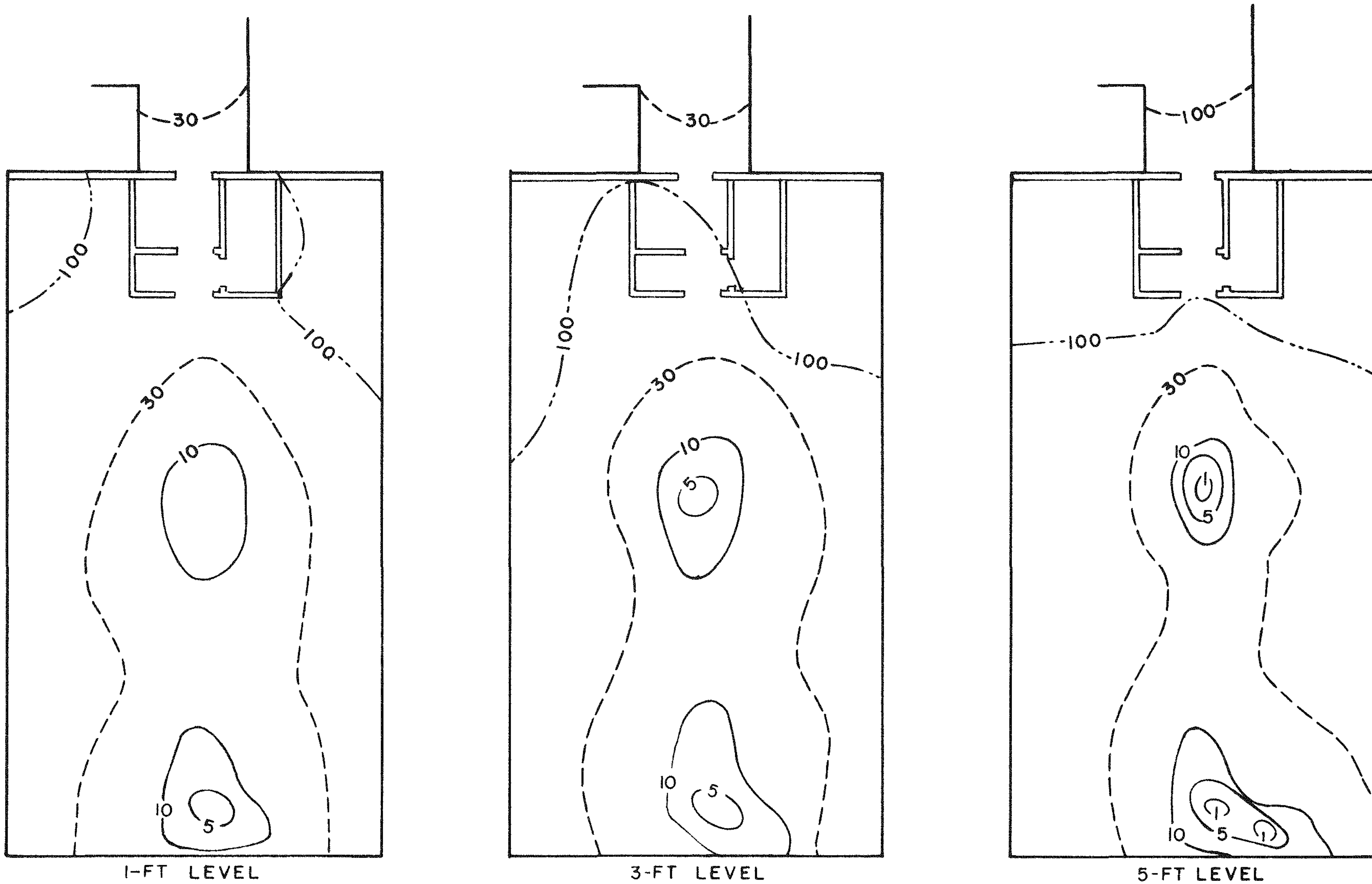


Fig. 4.5—Protection factors at three heights in underground group shelter (multiply by 1000).

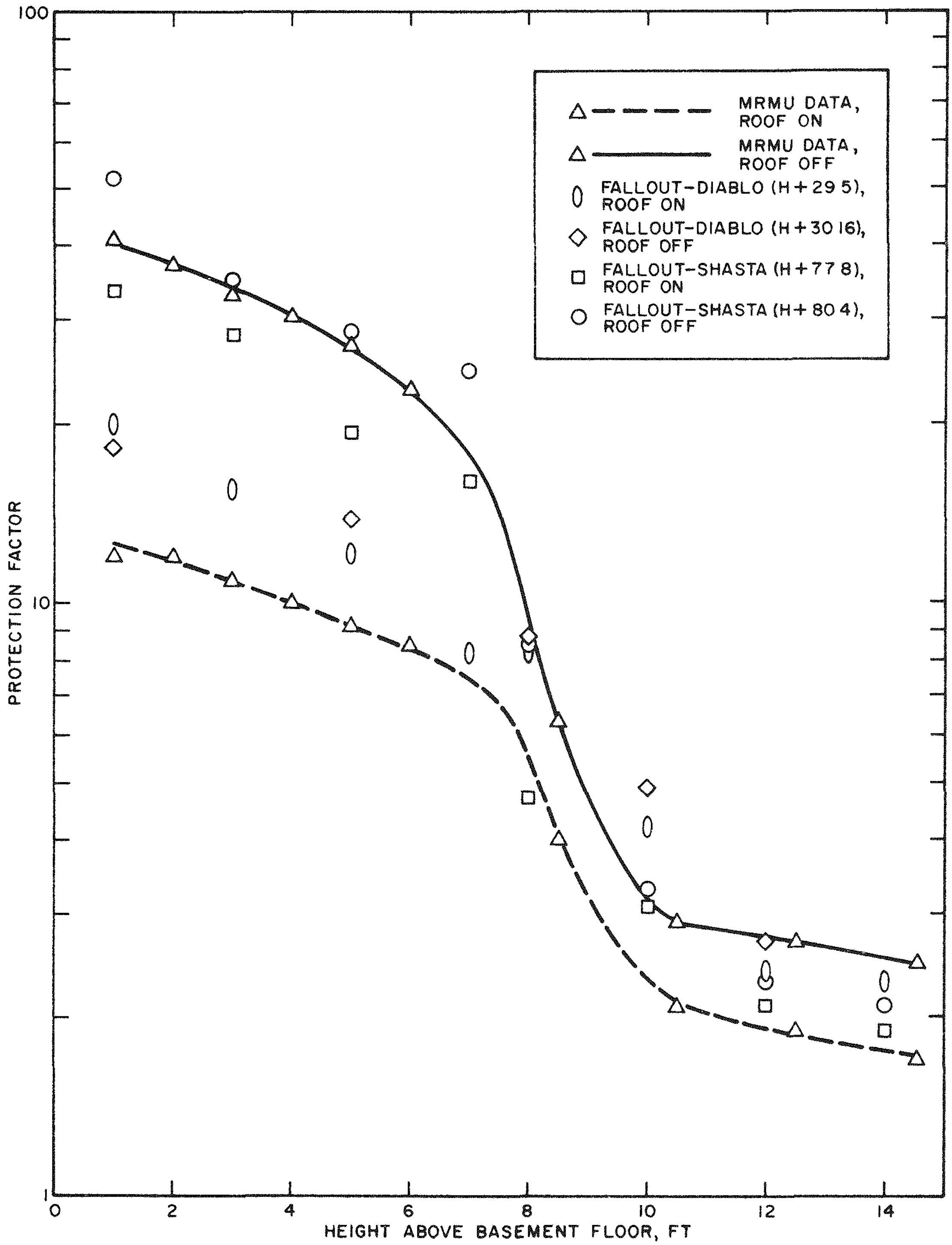


Fig. 4.6— Protection factors in center of Butler building.

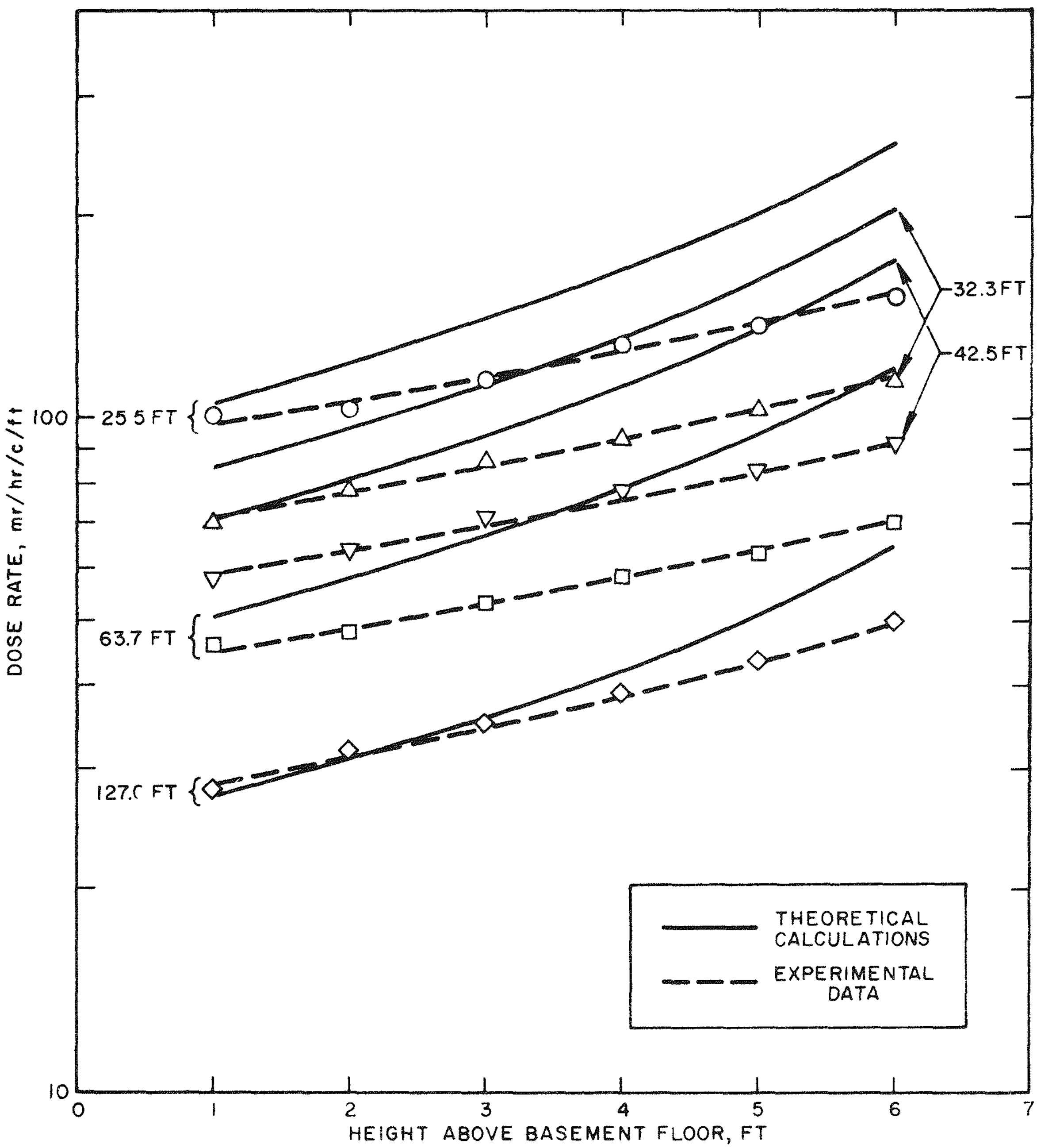


Fig. 4.7—Comparison of calculations and experimental data in center of Butler building.

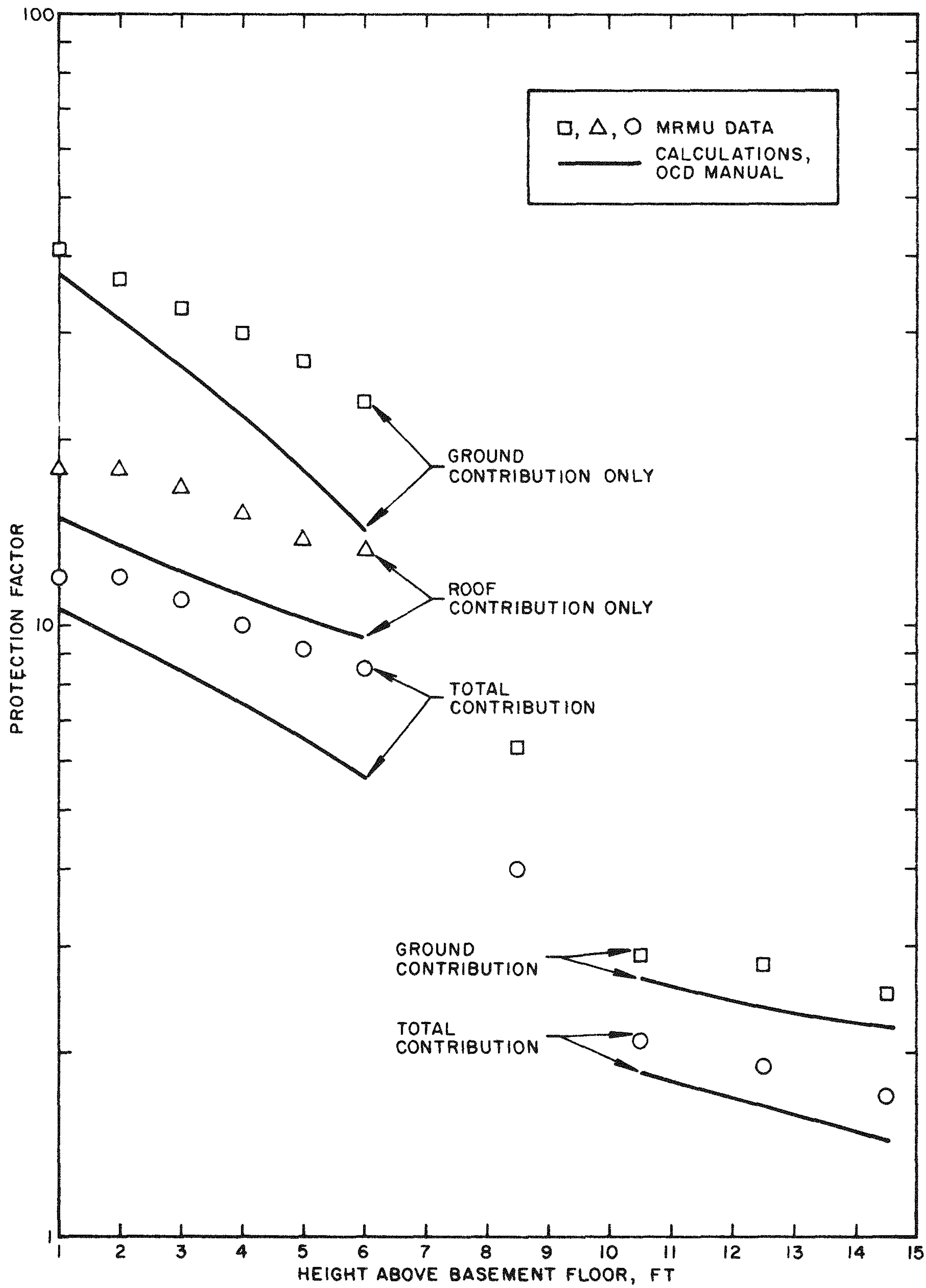


Fig. 4.8—Protection factors in center of Butler building.

Appendix A

MOBILE RADIOLOGICAL MEASURING UNIT

A.1 GENERAL

The MRMU was a mobile system used to simulate area sources or ring sources outside a structure while radiation levels were measured inside the structure.

The MRMU employed a moving radioactive Co^{60} source hydraulically pumped through polyethylene tubing. The tubing was laid over the area of interest in such a manner that the amount of tubing per unit area was constant. Since the source traveled at a uniform speed, an area of uniformly distributed radioactivity was simulated. Thus fallout radiation was simulated since, under ideal conditions, fallout is uniformly deposited over large areas.

A Co^{60} source was used for shielding studies because the energy of the gamma radiation emitted (1.17 and 1.33 Mev) approximated the effective energy of gamma radiation from fallout at early times after a detonation.

As the source was pumped through the tubing, radiation doses were accumulated on sensitive ionization chambers (dosimeters) at desired positions inside the structure. The use of these dose-integrating detectors made the total radiation dosage appear to be arising from an area source. This technique had the advantage of averaging local features of the terrain and of the building under test in much the same way as would a true fallout field.

The MRMU was also used to simulate a ring source at a particular radius around a structure by pumping the source through the tubing placed at that radius.

A.2 MECHANICAL EQUIPMENT

Equipment making up the MRMU system, mounted on a truck for mobility, consisted of a hydraulic pumping unit, a mile of tubing, source-position indicators, a remote-control console, Co^{60} sources, source containers, interconnecting cables, ionization chambers, charger-readers, and a 256-channel analyzer and associated equipment.

The MRMU equipment was installed in three vehicles. The hydraulic system and source shields were mounted on one truck. Tubing reels and cable reels were mounted on a caisson trailer. A laboratory truck (Fig. A.1) contained the control console, data-readout equipment, tools, supplies, and general equipment for the system. The entire system was practically self-sufficient. The hydraulic pumping system consisted of a 120-gal reservoir, a 1-hp 220-volt electric motor, a piston type positive-displacement pump, filters, several hand-operated and electrically operated solenoid valves, and connecting lines. The outside diameter of the source capsule was slightly less than the inside diameter of the tubing, and thus a flow system rather than a pressure-differential system was used. In normal operation the internal pressure was approximately 100 psi when 3000 ft of tubing was used; the source traveled at 120 ft/min.

Cobalt-60 source strengths from 100 mc to 300 curies were used, as required, according to the type of structure being measured and the precautions necessary to minimize personnel exposure.

All Co^{60} sources were encapsulated in magnetic stainless-steel containers (slugs) accurately machined to pass through the plastic tubing. The large (300-curie) source was doubly encapsulated (a capsule within a capsule). It was approximately 2 in. long (Fig. A.2). The capsules were Heliarc-welded and passed all AEC leak tests.

Shielded storage was provided for the sources when they were not being used. Figure A.3 shows the 300-curie Co^{60} source shield. Within this shield were two S-shaped stainless-steel tubes in which the slug traveled. Stops were provided in the center of each tube to halt the motion of the slug when it returned to the shield. A means had been provided to secure and lock the source in place when it was not being used. Two source shields, an air compressor (used to empty the water from the tubing), and the hydraulic system were mounted on the same truck (Fig. A.4).

The slug was conveyed by water (antifreeze was added to the water in cold weather) through $\frac{1}{2}$-in. Marlex (high-density polyethylene) tubing, rated at 200-psi hoop stress at 130°F for a 1-year period. Burst pressure was rated in excess of 1000 psi. The tubing bend radius was usually limited to a minimum of 2 ft to ensure safe passage of the Co^{60} source.

An emergency hand pump (Fig. A.5) could have retrieved the slug from either direction if the main pumping unit had failed during actual operation.

The hydraulic pumping system was remotely controlled from the console (Fig. A.6) in the laboratory truck a safe distance from the pumping system. On the panel of the console was a series of lights which were connected individually to magnetic position indicators (Fig. A.7) on the tubing. These lights indicated the exact location of the source at any time. The control system could start, stop, or reverse the movement of the slug, with maximum speed obtainable in either direction.

Dosimeters in the building accumulated the radiation doses as the source traveled through the tubing. Figure A.8 presents an operational diagram of the MRMU system.

A.3 INSTRUMENTATION

Instruments used for radiation measurements in a structure included dose-integrating ionization chambers with associated charger-readers (Fig. A.9).

Approximately 250 Victoreen model 362 chambers (0- to 200-mr pocket ionization chambers) and 140 Victoreen model 239 chambers (0- to 10-mr stray-radiation chambers) were used in this experiment. Victoreen model 287 minometers were used for charging and reading these chambers.

The chambers were calibrated with a Co^{60} standard. A number of chambers were selected at random and exposed several times to obtain an average dose and standard deviation at several points over the range of the instruments. Figures A.10 and A.11 present calibration curves for the two types of chambers, at standard temperature and pressure (20°C, 760 mm).

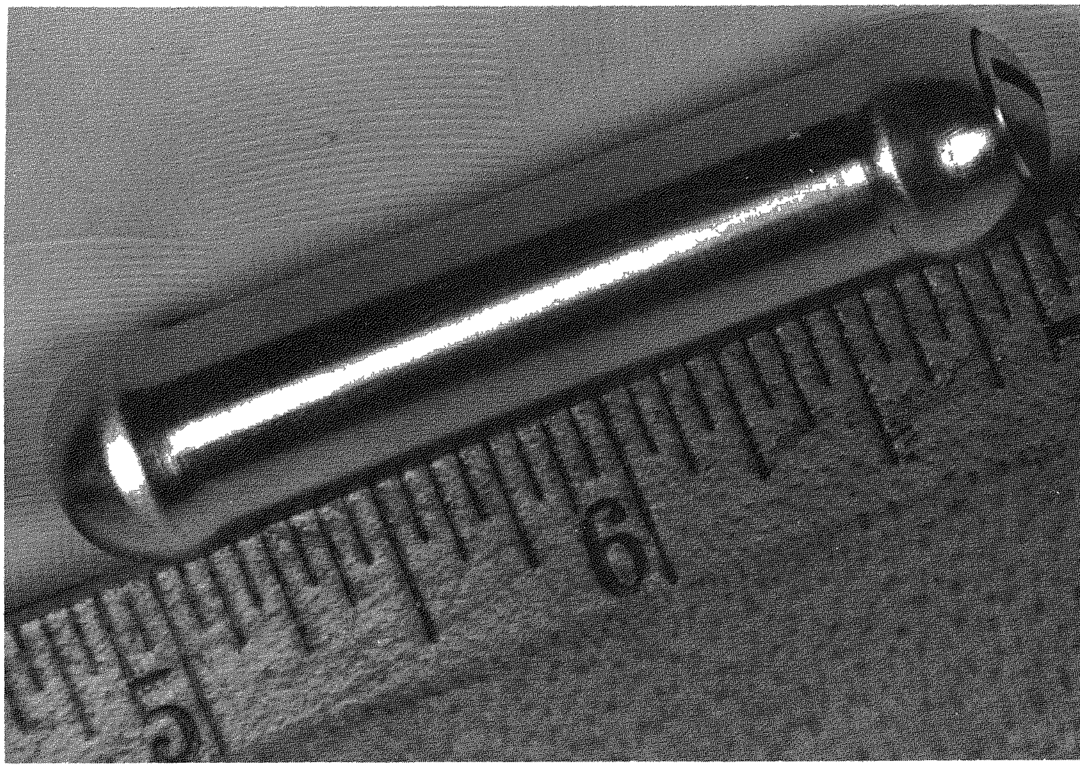
The energy and angular response of the low-range (10 mr) chambers were measured at the Santa Barbara laboratories of Edgerton, Germeshausen & Grier, Inc. The response curves are presented in Figs. A.12 and A.13. A discussion of the energy and angular response of the high-range (200 mr) chambers is found in Ref. 1.

Health physics monitoring equipment consisted of radiation meters, alarms, film badges, and pocket ionization chambers (Fig. A.14).

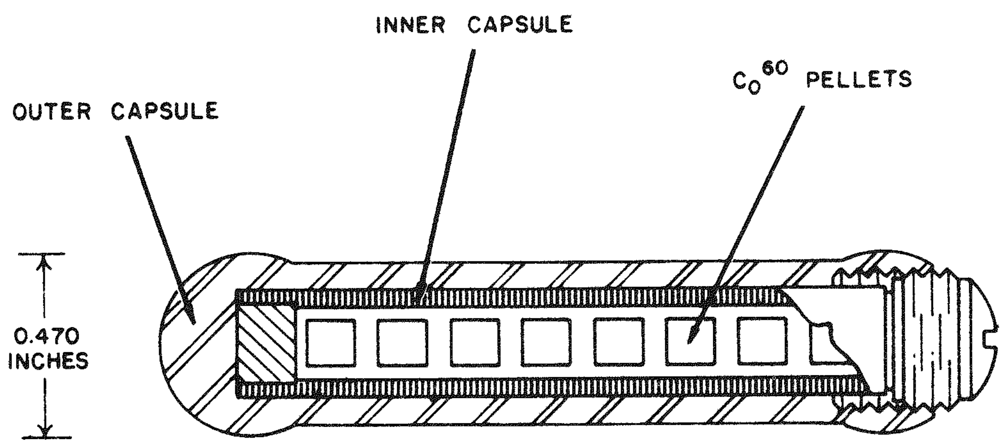
REFERENCE

1. F. W. Sanders, J. A. Auxier, and J. S. Cheka, A Simple Method of Minimizing the Energy Dependence of Pocket Ionization Chambers, *Health Phys., 2:* 308-309(1960).

Fig. A.1 — Laboratory truck.



(a)



(b)

Fig. A.2—(a) The Co^{60} source capsule. (b) Cutaway view of the Co^{60} source capsule.

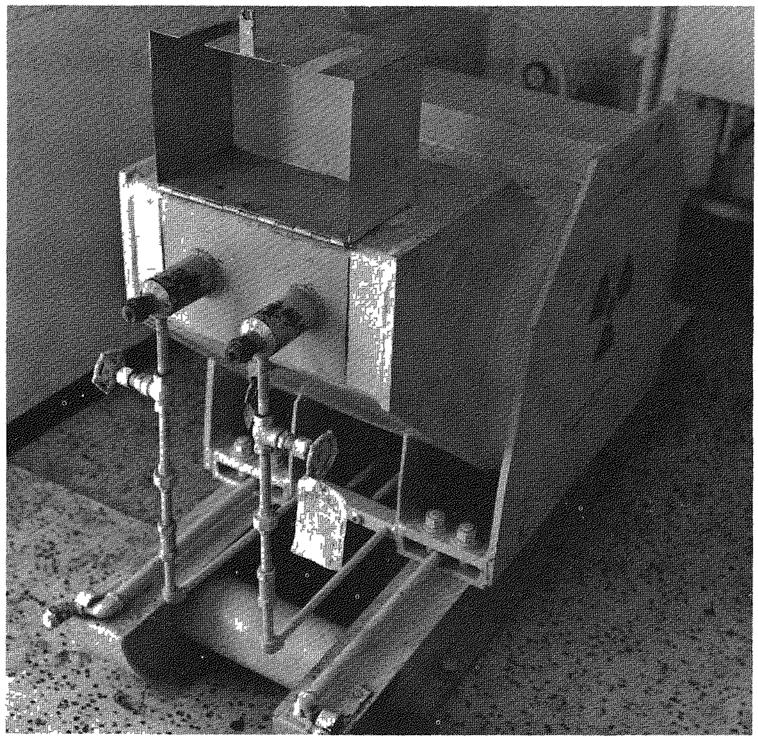


Fig. A.3—Large Co^{60} source shield.

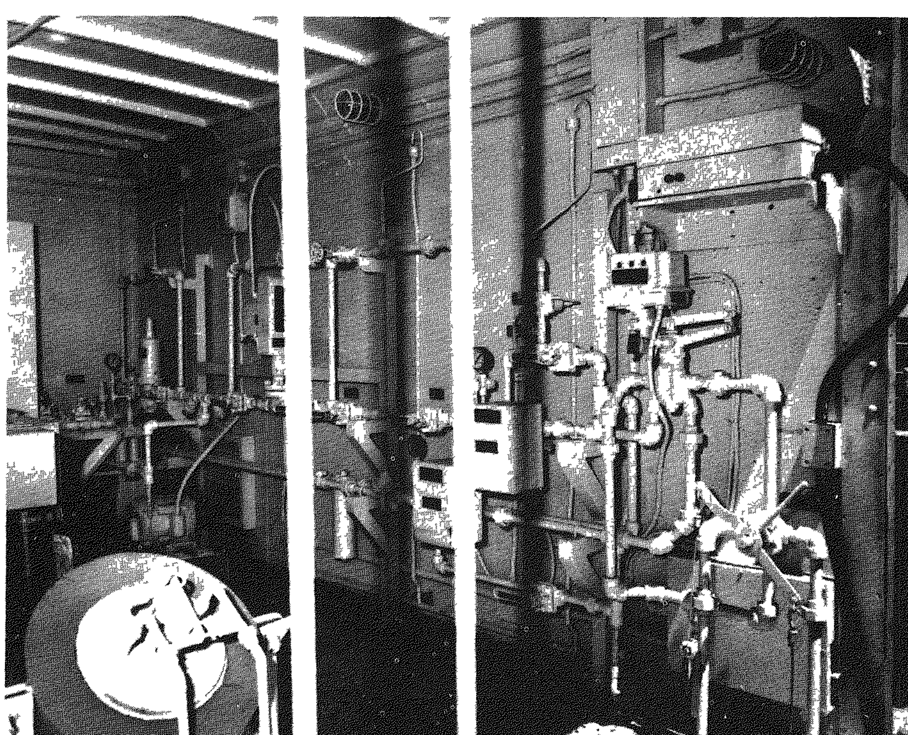


Fig. A.4—Source truck, showing shields and pumping system.

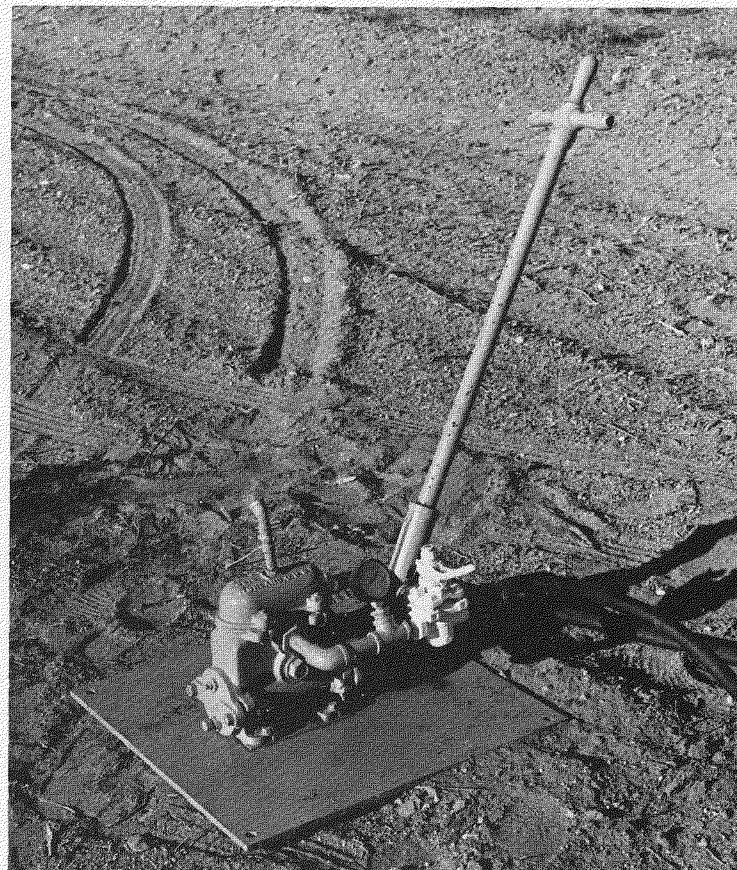


Fig. A.5—Emergency hand pump.

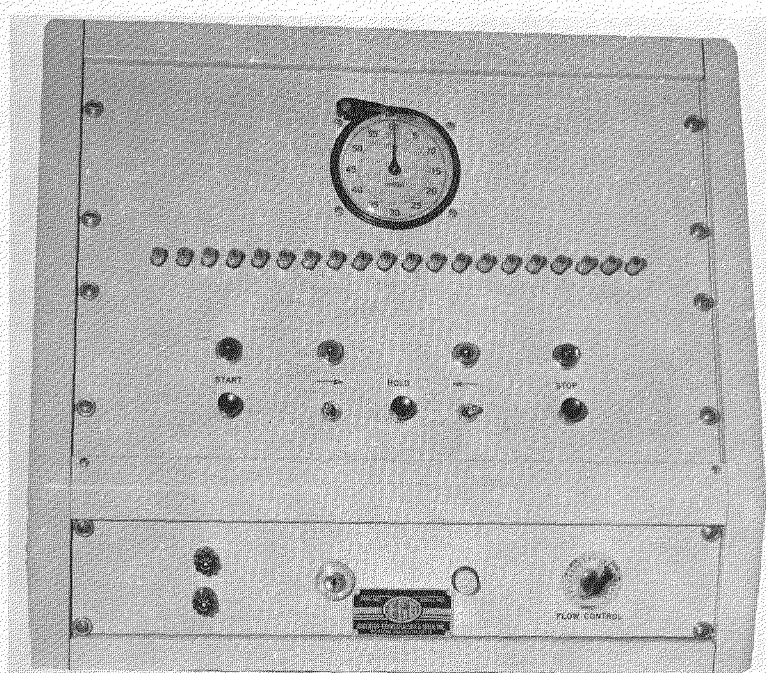


Fig. A.6—Remote-control console.

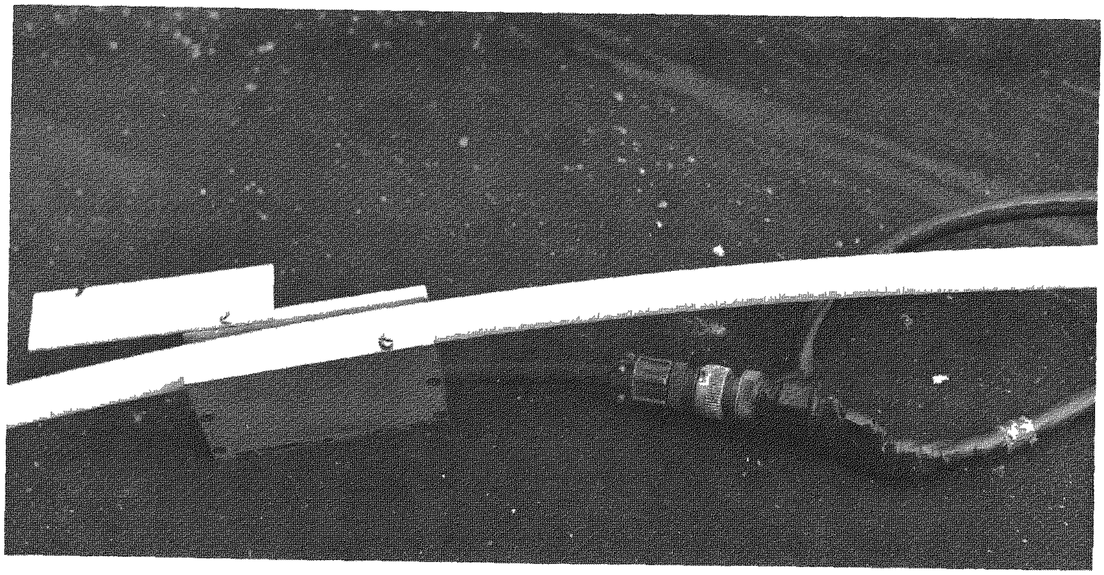


Fig. A.7—Source-position indicator.

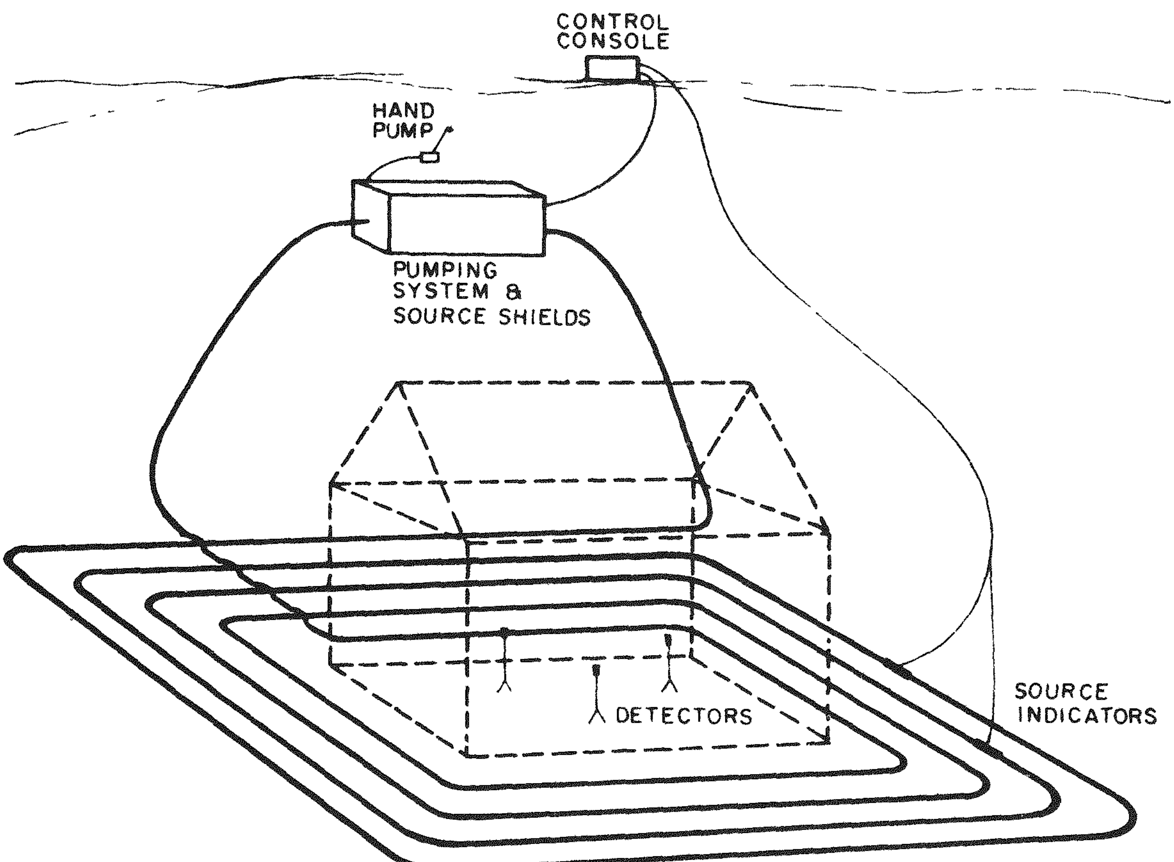


Fig. A.8—Operational diagram of the MRMU system.

Fig. A.9—Ionization chambers and charger-reader.

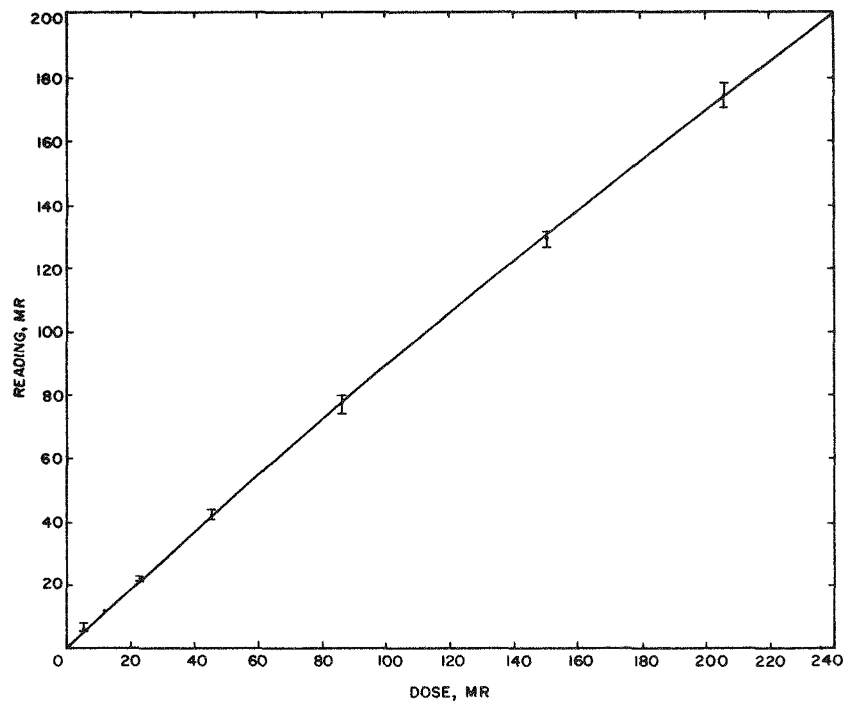


Fig. A.10—Calibration curve for the Victoreen model 362 ionization chamber.

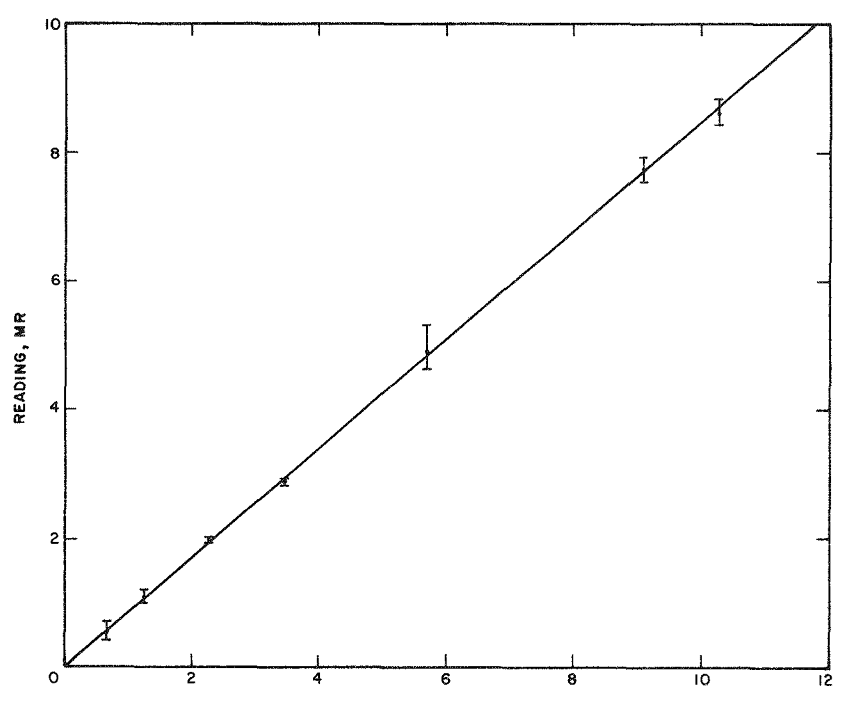


Fig. A.11—Calibration curve for the Victoreen model 239 ionization chamber.

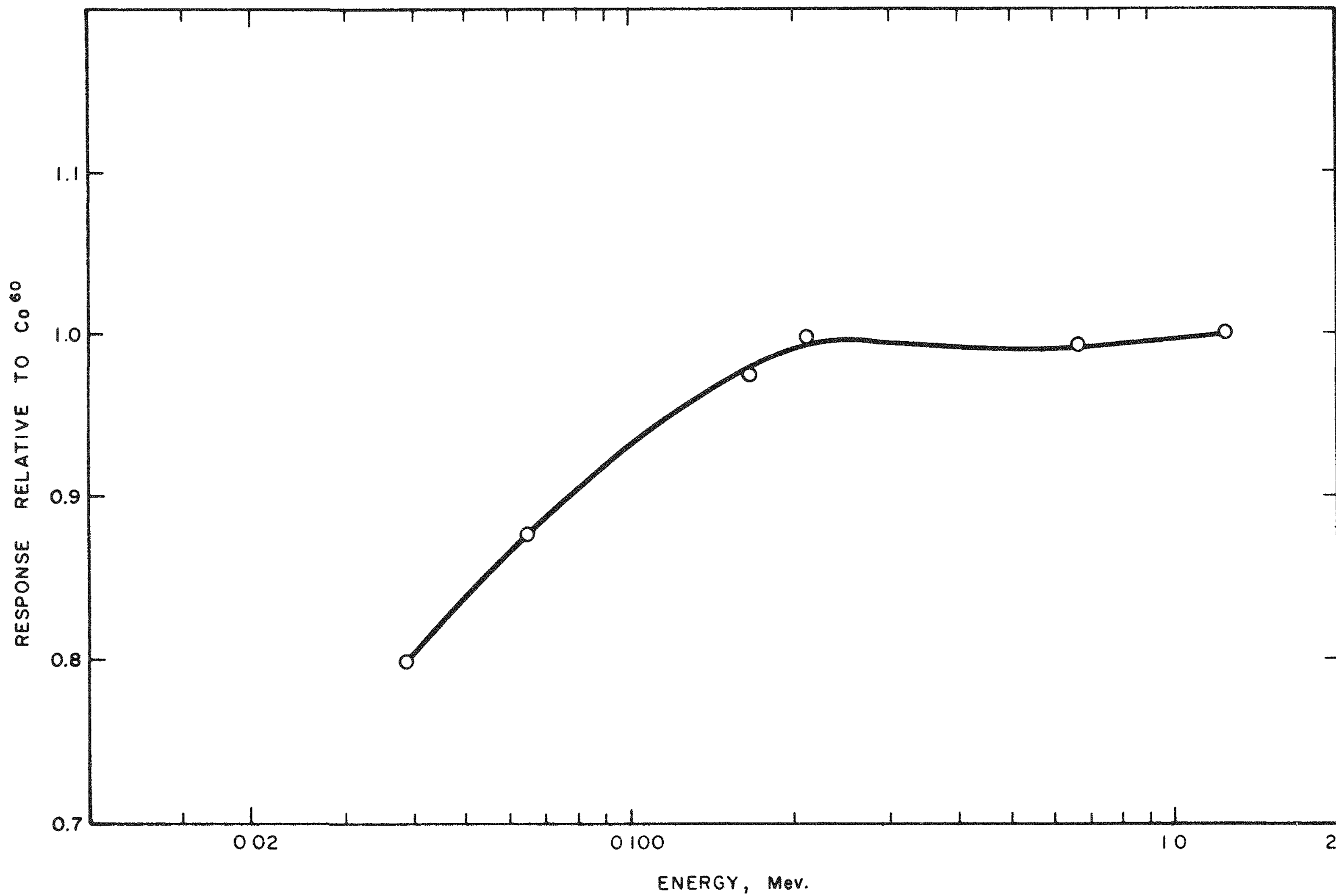


Fig. A.12—Energy-response curve of the Victoreen model 239 chamber.

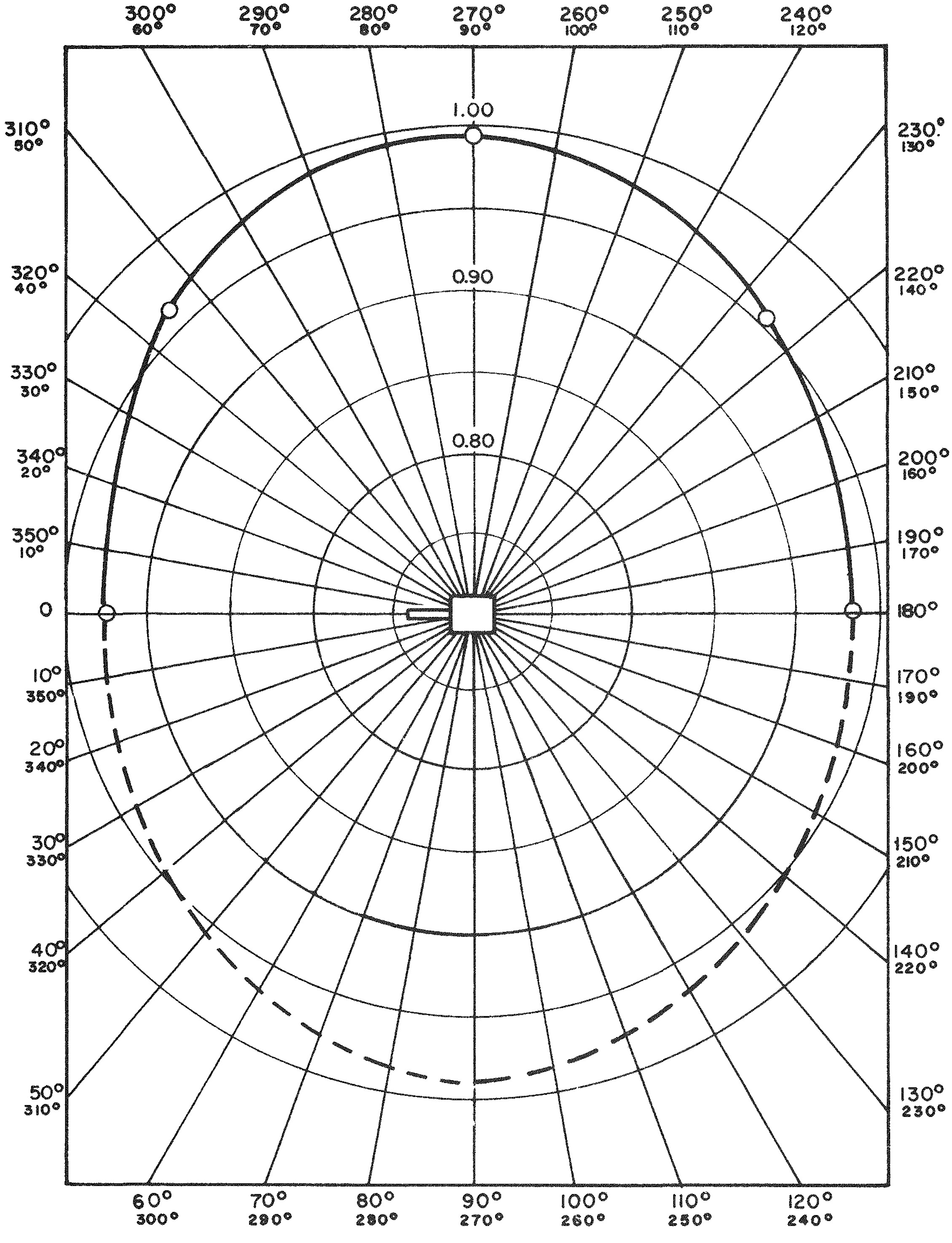


Fig. A.13—Relative angular response curve with Cs^{137}, Victoreen model 239 chamber.

Fig. A.14—Health physics equipment.

CIVIL EFFECTS TEST OPERATIONS REPORT SERIES (CEX)

Through its Division of Biology and Medicine and Civil Effects Test Operations Office, the Atomic Energy Commission conducts certain technical tests, exercises, surveys, and research directed primarily toward practical applications of nuclear effects information and toward encouraging better technical, professional, and public understanding and utilization of the vast body of facts useful in the design of countermeasures against weapons effects. The activities carried out in these studies do not require nuclear detonations.

A complete listing of all the studies now underway is impossible in the space available here. However, the following is a list of all reports available from studies that have been completed. All reports listed are available from the Office of Technical Services, Department of Commerce, Washington 25, D. C., at the prices indicated.

CEX-57.1 ($0.75)	The Radiological Assessment and Recovery of Contaminated Areas, Carl F. Miller, September 1960.
CEX-58.1 ($2.75)	Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, J. A. Auxier, J. O. Buchanan, C. Eisenhauer, and H. E. Menker, January 1959.
CEX-58.2 ($0.75)	The Scattering of Thermal Radiation into Open Underground Shelters, T. P. Davis, N. D. Miller, T. S. Ely, J. A. Basso, and H. E. Pearse, October 1959.
CEX-58.7 ($0.50)	AEC Group Shelter, AEC Facilities Division, Holmes & Narver, Inc , June 1960.
CEX-58.8 ($1.00)	Comparative Nuclear Effects of Biomedical Interest, Clayton S. White, I. Gerald Bowen, Donald R. Richmond, and Robert L. Corsbie, January 1961.
CEX-58.9 ($1.25)	A Model Designed to Predict the Motion of Objects Translated by Classical Blast Waves, I. Gerald Bowen, Ray W. Albright, E. Royce Fletcher, and Clayton S. White, June 1961.
CEX-59.1 ($0.60)	An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building, J. F. Batter, Jr., A. L. Kaplan, and E. T. Clarke, January 1960.
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